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Essentials of Medical Electricity

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ESSENTIALS

OF

MEDICAL ELECTRICITY.

BY

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PREFACE.

THE writers of this manual lay no claim to originality. Some of the most distinctive points elucidated at great length in the exhaustive works of Erb, De Watteville, v. Ziemssen, Beard, and Rockwell, and others, have been partially digested, and an effort made to place them before the undergraduates in such a manner that they may form a general idea of the diagnostic and therapeutic value of electricity, concerning which they hear so much, and, many of them, know so little. If, in addition, a few post-graduates find their labors lightened, and points of practical utility stated in a sufficiently brief and intelligible form, then the object of this little digest has been fully attained.

The experience of the writers in teaching rather indicates that many students evince peculiar difficulty in grasping certain points of this subject, therefore an effort has been made to clear away some of the stumbling-blocks, even at the risk of being considered guilty of prolixity and reiteration. The apology offered is simply that the hope has been entertained that by bringing the same points before the reader in different connections the desired result may be more readily achieved.

ESSENTIALS OF MEDICAL ELECTRICITY.

PART I.

GENERAL ELECTRO-THERAPEUTICS.

THERE exists no one topic in the boundless expanse of scientific investigation that has encountered more earnest and persistent inquiry than the one now proposed for consideration. Notwithstanding the vast amount of research and experimental work accomplished, and the brilliant results thereby achieved in its application, no satisfactory definition of electricity has as yet been announced; furthermore, it would appear that, however desirable such a result may be, its attainment seems still quite remote. As a partial approximation thereto the assertion is made that galvanic electricity is a form of molecular motion, and galvanism is probably the most important branch of medical electricity. Minute and painstaking experimentation has placed certain facts beyond dispute. While old theories may be overturned and new ones dominate in turn, many constitutional laws as now fixed must always remain unchanged. It has been long customary to look upon electricity as a fluid, and it must be allowed that in many important characteristics the resemblance is well sustained. Electricity exists in three forms —Galvanic, Faradic, and Franklinic or Static electricity.

Discovery of Galvanism.

Galvanic or Voltaic electricity receives its name from the early observers Galvani of Bologna and Volta of Pavia, between whom an earnest controversy existed as to the origin of the phenomena. Volta held that the galvanic current was caused by the contact of two dissimilar metals; but this theory is rejected by scientists of the present day. On the other hand, Galvani claimed that the results produced by him were due to electricity generated in the animals on which he operated. It remained for Fabroni, of Florence, to first intimate that chemical action was really its source; and he ennunciated this opinion whilst observing the action taking place in the pile invented by Volta about one year before the latter's death. Many eminent scientists of that day supported this view, and among them was Sir Humphry Davy. About the year 1807, Sir H. Davy obtained by electrolysis the elements potassium and sodium; and thereafter discoveries followed in rapid succession, owing to the labor of such tireless workers as Dulce, Zamboni, and Oerstead, until a culminating point was attained in 1827, when Ohm announced the law which has since borne his name. Mathematical accuracy as applied to electricity then for the first time assumed its position.

The phenomena of galvanism can perhaps be most clearly demonstrated by constructing a cell of simple form and observing its action. For this purpose there should be provided a strip each of copper and zinc, a glass jar, some copper wire, and hydrochloric acid. The jar being filled with a dilute solution of the acid, the zinc plate is immersed therein, with one extremity to which a wire may be attached projecting above the surface. Chemical action at once ensues, the acid acting upon the zinc, the result being zinc chloride and hydrogen gas. The gas collects in fine bubbles upon the metal plate, and as rapidly as they are evolved arise to the surface of the solution; the zinc chloride of course remains dissolved. After a time the zinc plate, if weighed, will be found to have lost precisely in weight the amount of zinc found combined in solution as zinc chlo-

ride. The second step in our demonstration involves the immersion in the same vessel of the strip of copper. It should be placed near and parallel to the zinc, but should at no point come in contact therewith. One end, provided with means for attachment of a wire, should, like the zinc, remain above the surface of the fluid. Upon this being done, an immediate and decided change is observed. Bubbles of hydrogen are no longer seen to collect upon the surface of the zinc, but they do appear upon the copper plate; zinc chloride, however, still continues to be formed. Now let the plates be weighed, and the copper will be found intact; the zinc still diminishes, and the loss is found to bear the same relation to the amount of the element combined in solution. We will now proceed to remove the zinc plate and substitute therefor one of iron. Precisely the same action will be observed, except that iron chloride will result in place of the same salt of zinc; hydrogen will collect, just as before, upon the surface of the copper element. Now let the copper be removed and zinc take its place: a change will at once occur, the hydrogen bubbles now being evolved upon the iron. Thus it would appear by the first experiment that hydrogen and zinc chloride are both formed at the zinc plate, but that the former is transferred to the copper upon the latter being placed in position: it likewise is evident that zinc is more actively attacked by the acid solution than copper. A proper test would also show that zinc is more assailable than iron, which in turn is more susceptible to the solution than copper; hence we conclude that the gas is formed chiefly at the plate most acted upon, but is evolved at the other—*i. e.*, we may perhaps be permitted to say *it flows* from one element to the other. If a magnetic needle be brought near a wire connecting the two elements, it (the needle) will at once be deflected from its normal position and tend to assume one at right angles to the wire; the needle will also be found to move in one direction or the other, depending upon the position of the wire and the relative connection of the two elements, *i. e.*, metal plates.

Production of Heat.

If a portion of the connecting wire consists of fine platinum wire, its temperature will be raised, and, under favorable circumstances, will become very high, approaching often the point of fusion.

Galvanic Couple.

The arrangement of two metallic plates in a solution which acts chemically upon one of them is called a simple voltaic or galvanic couple (Fig. 1). When the plates are disconnected—

FIG. 1.

FIG. 2.

i. e., not joined externally by a wire or other conductor—the circuit is said to be open (Fig. 2). When the plates are joined externally by a conductor, the circuit is said to be closed.

When the circuit is closed, the current is said *to flow from* the metal most actively acted upon by the solution *to* the other metal through that and the connecting wire back to the first.

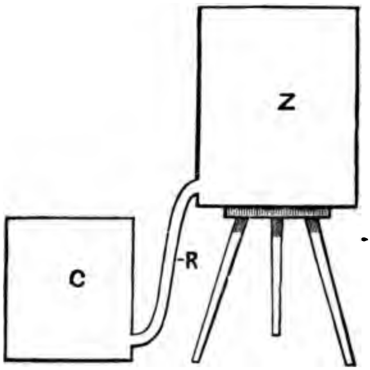
It is by no means requisite, in order to generate a galvanic current, that one metal should be impervious to the action of the acid; but it *is* necessary that one of the elements should be acted upon to a *greater extent* than the other. The element which is most susceptible to the action of the acid solution has been called the *positive* plate, and the other the *negative* plate. Besides the effect, already noted, upon the magnetic needle, a conducting wire connecting the two elements will be found to

possess other definite and remarkable qualities, the most important of which, in this connection, being sensory and motor influence upon animal tissue.

Potential.

The scientific definition of this peculiar quality of bodies, electrically considered, is somewhat difficult to conceive. Let it suffice to say that the difference of potential of two bodies is the peculiar electrical relation they bear to each other, and this relation is purely one of degree, for a substance which is electro-positive to one body may be electro-negative to another.

FIG. 3.



This is most happily illustrated by DeWatteville, who compares the potential of different bodies to reservoirs of water placed at unequal altitudes and communicating by means of pipes.

If the upper tank is filled with water, the fluid, obeying its own law, seeks a lower level and flows through the tube into the lower receptacle; hence the upper vessel represents the zinc or positive element, the tube the chemically acting fluid, and the lower vessel the copper or negative element. It is plainly to be perceived that *C* is negative to *Z;* but should we establish

and connect a still lower reservoir, *C* would become positive to it. The upper reservoir is of a higher potential than the lower. In the one case, the force of gravity is acting; in the other, the difference of potential.

For convenience of comparison the earth is considered to be of zero potential, and all bodies *from* which electricity flows *to* the earth are said to be of positive potential; while, on the other hand, all bodies to which electricity flows from the earth are of negative potential. *Potential* really represents *work done.* The potential of a body at a certain point is the amount of work expended in transferring one unit of positive electricity from an infinite distance to that point.

Electro-Motive Force.

Electro-motive force is the inherent force that starts the current and maintains it; *it is the difference of potential* between two bodies. It depends not upon the size of the elements, but upon the peculiar inherent quality possessed by each.

Current.

The result of this chemical action is a phenomenon called the electric or galvanic *current.*

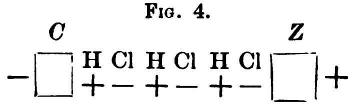
A *cell* consists of a proper vessel containing a fluid capable of acting chemically upon two metal plates of different potential immersed therein.

Poles.

In general, the metal most acted upon by the chemical fluid is called the positive plate, and the electrical current flows from it to the other or electro-negative element. If to each element a conducting wire is attached, the current will be diffused through them. *The extremity of each wire is a pole*, and inasmuch as the positive current generated by the zinc flows from it to the copper, the conducting wire from the latter becomes at its extremity the *positive pole.* The conductor attached to the zinc, or most active element, always terminates in the *negative*

pole. When the zinc and copper plates are immersed in the chemical fluid just mentioned, they at once become polarized, *i. e.*, assume opposite electrical conditions; the zinc becomes positive and the copper negative. But it must not be forgotten that, although this is the fact, still a conducting wire leading from the copper plate becomes the positive pole, for the previously explained reason that the positive current flows from the zinc through the fluid and on out through the copper and wire, thence back to the zinc; therefore if a wire connecting the two elements externally be broken in any part of its extent, the end leading from the copper or negative plate will be found to be the positive pole. When a copper and zinc plate are immersed in dilute hydrochloric acid, the compound molecules of the solution are assumed to take on a highly polarized condition, *i. e.*, the chlorine or negative part is attracted by the zinc, and the hydrogen or positive by the copper. The chlorine unites with the zinc to form zinc chloride; the hydrogen, however, forms no combination with the copper, but rises on its surface in bubbles. The fact that hydrogen leaves the fluid here and not at the zinc plate where it is formed can only be explained upon the hypothesis that an interchange of constituents in the fluid takes place between the two elements. Thus—

FIG. 4.



A difference of potential really exists between the acid solution and the zinc—likewise between the copper and solution; but the difference of potential is greater between the former than the latter; therefore the electric current is said to be established from the zinc to the copper. The positive element possesses a higher potential than the negative, and it is the *difference* of potential between the two elements that sets the electric current in motion and sustains it.

Resistance.

The *resistance* encountered by the diffusion of a current of electricity generated by a galvanic battery is of two kinds, viz. :—

1. **The internal resistance,** or impediment offered by the fluid contents of the cell through which the current passes and by the elements themselves.

2. **The external resistance,** or that offered by the connecting wire and all other substances whatsoever through which the current flows outside the cell. This is a subject the importance of which cannot be overestimated, and should be thoroughly grasped before further advance.[1] It is in this relation also that electricity bears a peculiarly striking resemblance to a fluid. Thus :—

1. If the surface of the elements is enlarged, the resistance offered by the intervening fluid will be found to be diminished, just as the resistance to the flow of water from one reservoir to another at a lower level will be diminished by enlarging the sectional area of the pipe connecting them.

2. The resistance will be less if the elements be brought close together. This is equivalent to shortening the connecting pipe of the reservoirs.

3. The external resistance will be diminished by increasing the sectional area of the connecting wire and by decreasing its length.

4. A good conductor offers less resistance than a bad one.

Hence the electrical resistance depends—

1. Upon the length of the conductor ; a long wire will offer more resistance than a short one.

2. Upon the thickness or sectional area of the conductor ; a thick wire will offer less resistance than a thin one.

3. Upon the peculiar or specific resistance of the conductor itself ; glass will offer greater resistance than copper.

[1] The student unfamiliar with the physics of electricity will find all subsequent reading decidedly facilitated by a careful study of "Electrical Resistance."

Conductors.

Metals are the best available conductors of electricity. Zinc, tin, and iron, named in their order of merit, head the list. Among those not conducting so well must be classed mercury. Carbon is a good conductor. Saline solutions and acids are much better conductors than pure water, and hot water than cold. Glass, silk, India rubber, etc. are very poor conductors, and are even used to insulate good conductors. The human body, excepting the skin, is a good conductor, owing to the fact that it is chiefly composed of saline solution. The skin is a very bad conductor ; its conductivity may be much enhanced, however, by means of a good conducting solution applied to the surface.

Capacity.

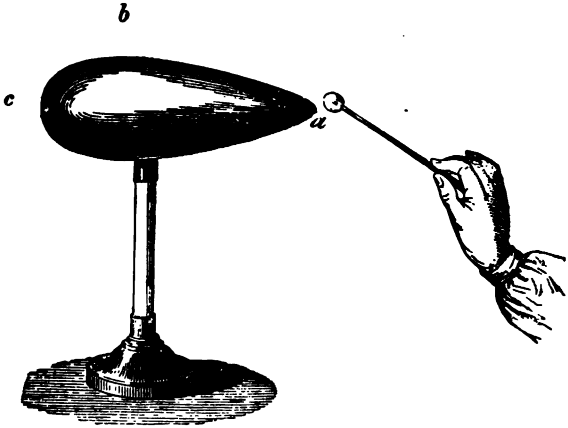
Electrical capacity may be looked upon as the greatest quantity of electricity which may possibly be acquired by a conductor when in contact with a body that charges it to unit electrical potential. We may have a large electrical capacity, and yet a very low electrical potential, and *vice versa.* This may be illustrated by comparing potential to temperature. A certain amount of heat will raise the temperature of a fine wire to a very high degree. The same quantity of heat, however, will not materially elevate the temperature of another body less easily heated ; for instance, a jug of milk. The latter will require much more heat to produce in it the temperature attained by the fine wire ; that is, the *capacity* of the jug of milk is much greater than that of the fine wire.

Density.

The electric density means the compactness of electricity existing upon the surface of a body. Upon a sphere the density is equal at all points. Upon an ellipsoid the density varies at different points. Thus, in Fig. 5, the electric density would be found greatest at *a*, not so great at *c*, and least at *b*. If *a*

represents a point, it would possess the utmost attainable density, and, in fact, might be considered to have reached infinity. As density increases the tendency of the electricity to overcome

FIG. 5.



the resistance offered by the air increases, and when finally that resistance is overcome the electricity escapes. If the escape occurs in the dark, it appears luminous.

Ohm.—*The unit of measure of resistance* is called an *Ohm.*

Volt.—*The unit of measure of electro-motive force* is called a *Volt.*

Ampere.—*The unit of measure of current strength* is called an *Ampere.*

One Ampere is the strength of current furnished by the electro-motive force of one Volt passing through one Ohm of resistance; that is, by Ohm's law and using units we have $\frac{1}{1} = 1$. In practical work the Ampere is measured by the amount of water the current will decompose into oxygen and hydrogen in one second at 0° C. temperature, and 760 mm. pressure; under these conditions one Ampere will set free 114.6 c.mm. of

hydrogen and 37.3 c.mm. of oxygen. It also performs other definite qualities of work, such as deflecting the magnetic needle, etc.

One Volt is equal to *about* the electro-motive force of a newly charged Daniel's cell. The Volt bears the same relation to an electric battery that the horse-power does to an engine.

One Ohm represents *nearly* the resistance offered to an electric current by a coil of copper wire 1 mm. in diameter and 48.5 mm. in length.

Current Strength.

From what has been said above it must be evident that the strength of every electric current must bear an unalterable relation to the amount of resistance it encounters; and to Ohm we are indebted for the law governing this problem. He found that any current of electricity is equal to the electro-motive force divided by the sum of the resistances; that is, if

$$\begin{aligned} c &= \text{the current,} \\ e &= \text{electro-motive force,} \\ ir &= \text{internal resistance,} \\ er &= \text{external resistance,} \end{aligned}$$

the law will be expressed thus: $C = \frac{e}{ir + er}$. This law is of vital importance, for it is the basis of *all* electrical calculations.

A GALVANIC BATTERY is a collection of two or more galvanic cells connected together in such a manner that the electricity generated by all can be conducted through one wire.

The strength of current under varying circumstances depends greatly upon the manner in which the cells are arranged.

Measurement of Currents.

Starting with this data the measurement of an electric current and the proper arrangement of cells can be accomplished with facility. This in medical electricity is a matter of much moment.

Milliampere. *The milliampere*, or one-thousandth part of an ampere, has been universally adopted as the working unit among physicians, and it has very great advantages in practice; for instance, the current generated by three Daniel's cells through the average resistance of the human body with moderate-sized electrodes equals about one milliampere.

Simple Circuit Arrangement. This is an arrangement of cells in which the positive plate of one cell is connected to the positive of the next, and the negative plate of one to the negative of the other, and finally all the positives to all the negatives. This is practically forming one large cell with elements equal in size to the sum of the areas of all the elements, but the electromotive force remains the same as for one cell. See Fig. 6.

FIG. 6.

FIG. 7.

Compound Circuit Arrangement This is an arrangement of cells in which the positive plate of one cell is connected with the negative plate of the next, and so on through the whole number of cells to be used; the final connection being that of the positive of the first cell to the negative of the last cell. In this arrangement we possess a battery with an electro-motive force

increased as many times as we have number of cells and with an internal resistance also increased in the same proportion. See Fig. 7.

Arrangement in Sets. If it is desired to arrange fifty cells in *sets* of ten, the cells are divided into five lots; each lot is arranged in simple circuit which gives as a result five separate batteries, the elements of which are ten times greater in area than the elements of a single cell; the five batteries are now looked upon as five large cells, and these are arranged in compound circuit. The resulting battery has an electro-motive force five times greater than a single cell; the internal resistance of each resulting large cell is ten times less than a single original cell, but in the compound circuit this fraction is multiplied by five.

Effect of the Resistances upon the Current.

This can be understood very readily by means of a few simple calculations. In the first place, it must be remembered that any current is, by Ohm's law, equal to the electro-motive force of the battery divided by the resistance—thus $c = \frac{e}{ir + er}$; hence, to render the result greater, we must do one of two things: increase the numerator—*i. e.*, electro-motive force; or diminish the denominator—*i. e.*, resistance; either will result in an increased answer or current. To render the result of our fraction smaller, the reverse must be accomplished—*i. e.*, the numerator must be diminished or the denominator increased. This, in a nutshell, is the object of the different arrangements of cells, to adapt the current to greater or less external resistance.

Arrangement of Cells for Great External Resistance.

When, for instance, the electrical current is used for medical purposes, the resistance met with in penetrating the human body is very great. We will proceed to determine which arrangement

of cells will produce the greater strength of current under these circumstances. Let us assume that our electro-motive force equals 1 our internal resistance 20, and our external resistance (human body) about 3000 ohms; our current for one cell stands thus: $\frac{1}{20+3000}=\frac{1}{3020}$.

Now let us take forty cells arranged in compound circuit, which will give $\frac{1\times 40}{20\times 40+3000}=\frac{40}{800+3000}=\frac{40}{3800}=\frac{1}{95}$, a very great increase in current strength; for in this arrangement the electro-motive force and internal resistance are increased as many times as we have cells.

By connecting our forty cells in simple circuit we have—

$\frac{1}{\frac{20}{40}+3000}=\frac{1}{\frac{1}{2}+3000}=\frac{1}{3000\frac{1}{2}}$, a current that is inappreciably increased only over a single cell, because in this arrangement we have practically one large cell of the same electro-motive force and an internal resistance forty times less than the single cell; but the external resistance is so enormously out of proportion to the internal that we may diminish the latter very much without making any appreciable impression on the current. In fact, were such a thing possible, the internal resistance could be abolished entirely with but little effect upon the current, as seen in the example.

A very slight modification of the above will demonstrate the effect of an arrangement in sets. With the same external resistance let us assume an arrangement of fifty cells in sets of ten—thus $\frac{1\times 5}{\frac{20}{10}\times 5+3000}=\frac{5}{3010}=\frac{1}{602}$, or a much larger current than a simple circuit arrangement would produce, which is $\frac{1}{\frac{20}{50}+3000}=\frac{1}{3000\frac{2}{5}}$.

The effect of the internal resistance upon the current when the external resistance is very great may be illustrated by an example; thus, if one drop of water be added to a pail-full, the

increase would pass unnoticed ; but if one drop be added to one drop the quantity would be doubled. It is entirely for the same reason that the internal resistance may be decreased to any extent without evident effect upon the current if the external resistance is large. Hence, all galvanic batteries for therapeutical purposes are arranged in compound circuit. For other purposes, however, such as cautery, etc., the internal resistance assumes proportions of imminent importance.

Arrangement of Cells for Slight External Resistance.

Let the electro-motive force and internal resistance remain as above; let the external resistance be very small $=1$. From Ohm's law we have $c=\frac{1}{20+1}=\frac{1}{21}$; by increasing the number of cells—*i. e.*, *compound circuit* of forty cells, we have $\frac{1 \times 40}{20 \times 40 + 1}$ $=\frac{40}{800+1}=\frac{40}{801}=\frac{1}{20.002}$, while for one cell the result, as above, is $\frac{1}{20+1}=\frac{1}{21}$, demonstrating distinctly that, where the external resistance is slight, but little is gained in current strength by increasing the number of cells, but a very different result is achieved under similar circumstances if the *internal* resistance be diminished, *i. e.*, a simple circuit of forty cells, thus, $\frac{1}{\frac{20}{40}+1}=\frac{1}{\frac{1}{2}+1}=\frac{1}{1.5}$; or a very considerable increase of current strength. This arrangement is, we repeat, equivalent to the construction of one large cell with elements forty times greater in area than the original single-cell elements, and therefore having an internal resistance forty times less.

Equal External and Internal Resistance.

The external and internal resistances being equal, the current strength will be increased to an equal degree by enlarg-

ing the plates, or by increasing the number of cells; thus, $c = \frac{1\,(e)}{(ir)10 + 10\,(er)}$; by making the plates forty times larger (simple circuit), we obtain $\frac{1}{\frac{10}{40} + 10} = \frac{1}{\frac{1}{4} + 10} = \frac{1}{10}$ by multiplying the number of cells (compound circuit)—

$$\frac{1 \times 40}{10 \times 40 + 10} = \frac{40}{400 + 10} = \frac{40}{410} = \frac{1}{10.205} = \frac{1}{\frac{41}{4}} = \frac{1}{10\frac{1}{4}}$$

Recapitulation. A thorough comprehension of these principles is of such paramount importance that a brief restatement in as simple a manner as possible may, perhaps, be not out of place. In order to increase the current, we must, it is evident, make the electro-motive force greater in proportion to the *sum* of the resistances; if the external resistance is very considerable, as when the human body forms part of the circuit, it is obvious that but little can be gained by decreasing the internal resistance. To make this plain a very simple fraction may be assumed.

Let $e = 1$
$ir = 2$
(human body), $er = 3000$;

then $c = \frac{1}{2 + 3000} = \frac{1}{3002}$. Now to diminish the internal resistance, one-half would give us, $c = \frac{1}{1 + 3000} = \frac{1}{3001}$, so slight a gain as to be inappreciable. There is but one other resource— *i. e.*, to increase the electro-motive force; instead of dividing the internal resistance by two, let us multiply the electro-motive force and internal resistance by two,[1] and we have $\frac{1 \times 2}{2 \times 2 + 3000}$ $= \frac{2}{4 + 3000} = \frac{2}{3004} = \frac{1}{1502}$, or nearly double strength of current. Therefore, it follows that the best results can be obtained from a battery when the internal and external resistances are as nearly equal as possible, and the following facts may be enun-

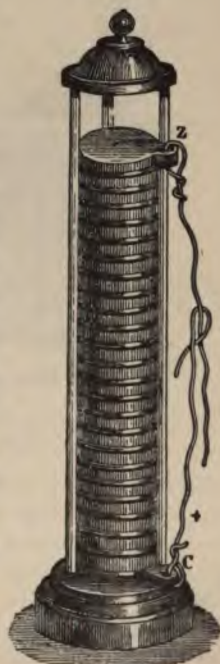
[1] Which may always be done by arrangement in compound circuit.

ciated: *To obtain an increase of current, when the external resistance is great in proportion to the internal, the number of cells must be increased* (*compound circuit*). *To obtain an increase of current, when the external resistance is slight, the size of the plates must be increased* (*simple circuit*). *When the object to be attained is heat*, as in the electro-cautery, the external resistance is very slight; hence, every object is gained by a few cells in simple circuit having elements with large surfaces. *When the internal and external resistances are equal*, the current may be equally modified by either increasing the number of cells or by enlarging the area of the elements.

Batteries.

Many batteries of various construction have been advocated by different observers, and present their several points of interest to the student. One of the earliest is the *voltaic* pile.

Fig. 8.



The Voltaic Pile.

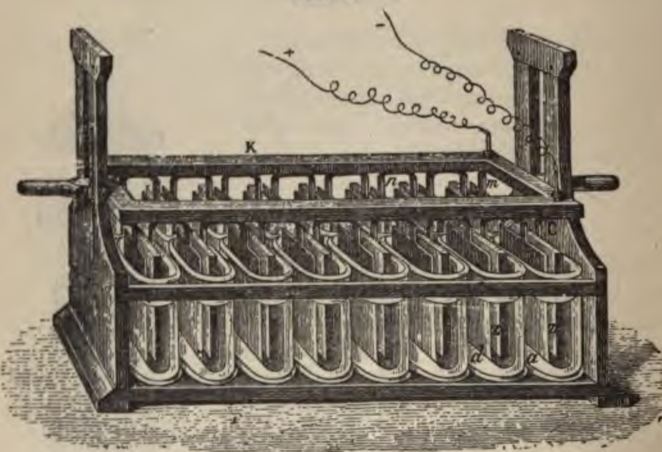
Upon a wooden base a plate of copper is laid, and upon that a strip of cloth, saturated with dilute acid or saline solution; upon the cloth in turn is placed a plate of zinc, and so on until a sufficient number of sets are secured in position, each set beginning with copper and ending with zinc, the order of copper saturated cloth zinc being maintained. The current flows from the zinc through the saturated cloth to the copper, and if the first zinc and last copper are connected by means of a wire, the current will flow through it from the latter back to the former, forming a circuit. It is important in constructing the pile that the zinc and copper plates between which no satu-

rated cloth intervenes should be soldered together, otherwise some acid solution would interpose and tend to set up an electrical current in the reverse direction. Fig. 8 shows the voltaic pile. *C* represents the copper plate resting upon a wooden platform, *w*; *a*, the acidulated strip of cloth, and *Z* the zinc plates.

The Trough Battery.

This is merely a modification of Volta's pile, but much more convenient, and may be constructed thus: A trough of wood, hard rubber, or glass, is divided into several compartments,

Fig. 9.



Trough battery. *K* represents cover with *Z*, zinc, and *C*, copper plates attached. *a*, *d*, cells containing dilute acid.

which are filled with an acid solution ; to this a cover is fitted, on the under side of which are arranged copper and zinc plates, so connected in pairs that when the cover or lid is lowered into position upon the trough a zinc and copper plate is emersed into each compartment, thus forming a number of galvanic cells. By a very simple device all the cells may be connected together into an extremely useful galvanic battery. See Fig. 9.

Daniel's Cell.

One of the earliest so-called constant cells was constructed by Daniel about the year 1836; it has for a long time sustained its reputation as one of the most constant, though not most powerful, of cells. It consists of a glass jar, containing dilute sulphuric acid; into this fits a cylinder of zinc; within the cylinder is placed an earthenware porous cup, which is filled with a saturated solution of copper sulphate, and upon a shelf arranged for the purpose within the cup are placed crystals of copper sulphate, or they may be contained in a little copper basket; into the solution a copper plate, also cylindrical in shape, is immersed; when the circuit is closed by means of binding screw attachments upon the plates and a wire, the acid acts upon the zinc forming zinc sulphate and liberating hydrogen, the latter, as we have previously seen, is transferred to the copper, and there liberated only to meet copper sulphate, which it at once acts upon,

FIG. 10.

Daniel's Cell.

forming sulphuric acid and metallic copper, the latter being deposited upon the copper plate. The porous cup is useful to prevent the transfusion of the saline solution; at the same time it allows the acid formed by the action of hydrogen upon the copper solution to permeate it and flow out into the acid solution surrounding the zinc element; this solution, weakened by

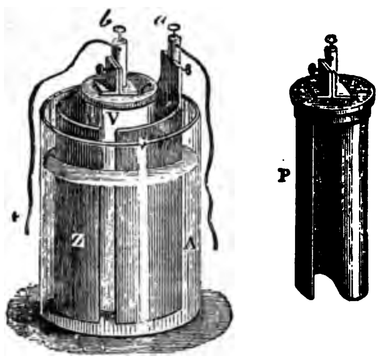
its constant action on the zinc, is as constantly replenished by fresh acid flowing out through the porous cup. See Fig. 10.

The electro-motive force of a Daniel cell is a little over one volt (1.12).

Grove's Cell.

This cell differs from Daniel's in that the sulphate of copper solution is replaced by nitric acid, into which is immersed a platinum instead of a copper plate; by this means a greater electro-motive force is secured.

FIG. 11.



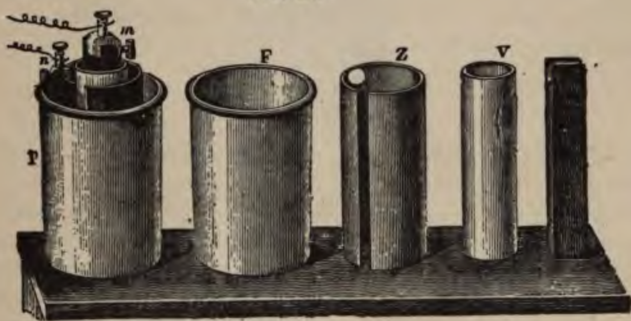
Grove's Cell.

Here the hydrogen generated by the action of sulphuric acid upon the zinc and transferred to the platinum element meets the nitric acid and decomposes it; hyponitrous acid is formed and passes off in fumes, constituting one of its chief objections. The platinum is not acted upon by the acid, but the zinc is liable to be rapidly consumed; careful amalgamation will tend to prevent this. The value of the Grove cell lies in its low internal resistance and high electro-motive force; but, on the other hand, the acid fumes are both annoying and dangerous; moreover, the electro-motive force will be found to diminish as the concentration of the acid solution grows less.

The Bunsen Cell.

This cell was constructed in 1843; it is practically a Grove cell with a carbon cylinder in place of the platinum plate. The carbon used is that found deposited in gas-retorts or made from coke and bituminous coal; it is a good conductor. A common Bunsen cell will give a current strength on short circuit of about 12 Amperes.

FIG. 12.



Bunsen's Cell.

The chemical action of a Bunsen and Grove cell is identical, and they are of equal power, but the Grove is less costly at first; this, however, is nearly equalized by its being more expensive to work and less convenient in its application.

Bichromate Cell.

In order to obviate the danger and annoyance incidental to the fumes of nitrous acid thrown off by the use of nitric acid, particularly when used in a confined atmosphere, chromic acid has been substituted, or, what answers still better, potassium bichromate and sulphuric acid.

Battery Solution.—An excellent solution for a battery of this sort is as follows: Four ounces of potassium bichromate, sulphuric acid four ounces, water eighteen ounces. Into this

solution is immersed the carbon plate, and the sulphuric acid surrounding the zinc element may be replaced by a saturated solution of common salt. The chemical action of this modification of cell is a little more complex than any of the preceding. Of course, the action of sulphuric acid on the salt of chromium produces potassium sulphate and chromic acid, hydrogen being evolved; that gas, acting with the chromic acid, forms water and chromic oxide; the latter combines with sulphuric acid to form chromium sulphate. This cell possesses high electric-motive force, and a battery composed of them is often preferred, owing to its convenience and the general satisfaction resulting from its use.

Smee's Cell

Is composed of a sheet of platinum between two of zinc immersed in dilute sulphuric acid; its peculiarity consists of the roughening of the platinum plate by a layer of finely divided platinum deposited upon its surface, which has an extraordinary effect in facilitating the escape of hydrogen from the plate, thus reducing the internal resistance and increasing the electro-motive force; it has been suggested that silver similarly treated with platinum would answer as well, and be less expensive.

Le Clanche Cell.

This cell is in great demand when continuous use is not required. It consists of a porous cup, in which is placed a carbon plate, tightly packed in manganese peroxide and gas graphite; a block of lead is soldered to the top of the carbon and attached thereto is a binding screw; the cup is then immersed in a vessel one-third full of a strong solution of sal ammoniac; the positive element consists of a rod of zinc having a copper wire attached. This cell develops an electro-motive force one-third greater than Daniel's, and a resistance of from 2 to 3 ohms. Continuous use soon polarizes it, but rest promptly restores its original power; for this reason, it is much used in *the construction* of electric bells.

Disadvantages of Carbon.—Embarrassment is sometimes caused by the formation of local currents at the junction of this element and the binding screw. This is due to the porosity of the carbon, and may be remedied by previously soaking the plate in

Fig. 13.

Le Clanche Cell.

hot paraffine, thereby closing the pores, but not impairing its conductivity. Of course, the surface should be thoroughly scraped to remove the external paraffine.

The Law Cell.

This is merely a modification of the Le Clanche, two circular carbon plates and a zinc rod being used ; the resistance is thus reduced, and, therefore, the current increased. This cell is now used by many in preference to any other.

Galvanic current developed by the action of one fluid on another.—This can be demonstrated by carefully filling one extremity of a U tube with nitric acid and the other with sulphuric acid ; both acids should be concentrated and care exercised not to permit admixture. If into each fluid a platinum plate is immersed and connected with a galvanometer, a current will be observed pass-

ing from the sulphuric acid to the nitric through the galvanometer.

Amalgamation of Zinc Element.—Zinc is an element of so much importance in the construction of batteries that it would be improper to leave this subject without referring to the necessity of having that plate well amalgamated. Pure distilled zinc is not attacked by sulphuric acid dilute, but, on the other hand, impure commercial zinc is freely acted upon and quickly dissolved in that solution. This is due to the fact that the ordinary zinc of commerce contains more or less iron or lead, and these metals, being electro-negative to zinc, set up small local currents, which hasten the chemical action, but do not result in any increase of the current in the connecting wire. To remedy this the plate is amalgamated, by means of which all impurities are removed from the surface. To accomplish this the plate should first be immersed in a solution of sulphuric or nitric acid to remove all extraneous matter, and then a small quantity of mercury dropped on the surface and thoroughly distributed over it by means of a brush, the plate will at once become amalgamated and assume the bright appearance of mercury. It is really coated with a solution of pure zinc in mercury ; by this means it is given the advantage of not being attacked by the solution of the cell so long as the circuit is open ; and when it is closed the current will be found more regular and stronger.

Dry Cell.—This cell has been much spoken of recently, and owing to its portability and convenience it is to be hoped that it may ultimately prove satisfactory and suitable to the various requirements of the practitioner. It is composed of a glass jar less than an inch in diameter and about three inches deep, having a double stopper, the lower one of resin-oil and resin, the upper one of plaster of Paris. The jar is filled with zinc sulphate made into the consistency of paste with flour; into this are dipped two plates of zinc, and between them a plate of silver chloride. The zinc is, of course, the positive plate, the silver chloride the negative, the connecting wire passing out through the stopper. These cells are claimed to give a constant current for quite an extended period, and to have an electro-motive force of about one volt. The resistance naturally

varies with the size of the plates. Thus far, the preponderation of evidence within the personal knowledge of the writers is decidedly against the practicability of this form of battery, it having been found in their hands unreliable. Fig. 14.

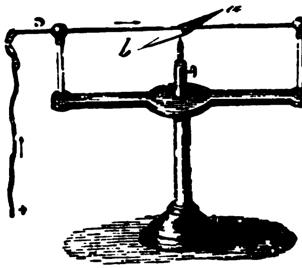
FIG. 14.

Galvanometer.

It is a matter of paramount importance that the physician should know exactly, or at least approximately, the size of the dose of electricity administered, and for this purpose a galvanometer must be used. This is an instrument which depends for its usefulness upon the principle that a current of electricity will deflect a magnetic needle from its normal position. The galvanometer will not only show that a current is passing, but it will measure its strength and indicatè its direction. Observations upon which this discovery depends were first announced by Oersted in 1819. He found that if a copper wire was extended in the magnetic meridian—*i. e.*, north and south, and a magnetic needle suspended immediately beneath it, in a condition free to revolve, so long as no current of electricity passed through the wire the needle remained stationary and parallel to the wire, but so soon as the wire was included in the circuit

of a galvanic battery the needle was deflected and assumed a position at an angle with the wire, and the stronger the electric current, the greater was the deflection, the tendency of the force acting being to cause the needle to take up a position at right angles to the one occupied whilst at rest.

FIG. 15.



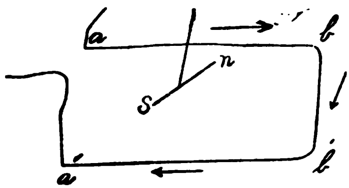
Deflection of the Magnetic Needle.—This is entirely governed by the direction and position of the current and by its strength. If the current passes parallel to and above the needle from south to north, the north pole of the magnetic needle is deflected to the west, if the current is flowing in the same direction, but below the needle the north pole deflects to the east. When the current flows above and from north to south, the north pole of the needle is forced toward the east, and if below in the same direction the needle swings to the west.

Ampere's rule is a most excellent and ingenious method of memorizing these facts. He fancies himself floating in the current of electricity, with his face always toward the magnetic needle, and in such a manner that the current flows in the direction from his feet to his head. In this imaginary journey the north pole of the needle is constantly on his left. It need not be added that as the swimmer turns with the current and finds himself under instead of above the needle he must of necessity turn himself and float upon his back in order to preserve the position of his face to the needle.

If a magnetic needle is delicately poised in the magnetic *meridian*, free to move and surrounded by a wire parallel to the

same (above and below), through which a current of electricity is passing, it will be seen that the portion of wire above and the portion below the needle tend to deflect it in the same direction, because the lower wire, of course, exerts an opposite force when the current flows in the same direction, but in this case the upper wire current flows one way while the lower one flows directly back in the opposite direction. Thus, the encircling wire exerts a double-power influence upon the needle, and it may be increased indefinitely by increasing the number of turns in the wire. This, however, is not without limit; for the resistance increases with the length of wire.

FIG. 16.



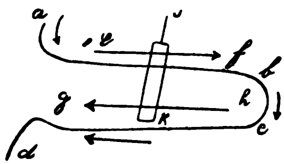
Let *a b b' a'* represent wire with current flowing in direction indicated by arrow ; it is plain, if the current were flowing from *a'* to *b'*, *i. e.*, in the same direction as in the upper wire, the two currents would oppose each other and the needle would remain unaffected; but the lower current flows from *b'* to *a'* ; thus, both the upper and lower currents exert their forces upon the needle in the same direction.

The Astatic System.

Let *e f* and *g h* (Fig. 17) represent magnetic needles immovably affixed to the strip *j k* and delicately suspended by a filament of silk; let *f* be the north pole of *e f* and *g* of *g h* ; let *a b c d* represent the conducting wire of a battery, the current flowing from south to north, as indicated by the arrows (of the upper portion of the conductor). By this arrangement the power of the earth to resist the effect of the current upon the needle is counterbal-

anced and the power of the current increased; for the effect of the current *a b* would be to deflect the needle *e f* to the east, the effect of the current *d c* would be to deflect the same needle to the opposite direction, both currents being below the needle and

FIG. 17.



flowing in opposite directions, but the current *a b* being nearer, and consequently acting with greater force, the former deflection occurs. As the current *a b* deflects the north pole *g* of the lower needle to the west the current *c d* does the same, or, what is equivalent, *h* is deflected to the east the same as *f*.

This arrangement is employed in the construction of an instrument of great delicacy. If the needles are exactly parallel, and have equal magnetic force, they will counterbalance each other, so that the earth will exert no influence; in other words, when only acted upon by the earth's magnetism, they will assume any position indifferently. However, it is practically impossible to arrange two needles precisely parallel; consequently, if their magnetic force be equal, they will come to a rest only when at right angles to the plane of the magnetic meridian.

The Multiplying Galvanometer

Depends upon the principle that magnetic needles are acted upon by a force multiplied by the number of turns in the coil of wire surrounding them (nearly), *i. e.*, only diminished by the resistance of the wire. It is important to bear in mind the fact that galvanometers vary with circumstances, *i. e.*, the number of turns in the coil, the thickness of the wire, and the variation in magnetism of the two needles; it is not desirable to

have the latter absolutely equal, because in that case the force exerted by the earth being entirely neutralized an exceedingly minute current of electricity would cause the needle to assume a position at right angles to the conducting wires. Hence, the power of the current under measurement to deflect the needle would depend in some degree upon the difference of magnetism between the two needles used in the galvanometer.

The Milliampere Meter has become the standard for measurement of electrical currents. It is practicable and convenient both as to name and calculation; its multiples accord well with the strength of current as used in medical application. The resistance of the human body is, under ordinary circumstances, about 3000 ohms. One milliampere is about the weakest current useful in practice through that resistance, and it is yielded

FIG. 18.

Miliampere Meter.

by from two to four Daniel's cells, a larger number of cells yielding a stronger current in proportion; hence, the current strength can be estimated in multiples of the milliampere, a convenient unit by which to express the amount of electricity

necessary to produce muscular contractures, etc., in electro-diagnosis. In this manner the important advantage is achieved of being enabled to compare results obtained by use of the same instrument or others of the same standard.

Fig. 18 represents a milliampere meter; the scale, it will be observed, extends from *o* in the centre to either side, the space between the divisions of the scale decrease as these divisions recede from zero. This is owing to the fact that the magnetic needle, or the earth through it, interposes a resistance to the deflecting power, which increases in strength directly in proportion to the amount of deflection; hence, each additional unit of strength of current will cause the needle to traverse a shorter space for each additional milliampere as the current increases.

Galvano-Therapeutic Outfit.

First in order of importance is to construct a good battery. For this purpose, perhaps, no cell will render more continued satisfaction than the Law. It is peculiarly fitted for a physician's use, owing to its quality of not becoming exhausted during disuse, and its power of recuperation, if allowed an interval of rest after use. It only requires an occasional supply of water or solution of ammonium chloride and at long intervals a renewal of the zinc plate. A battery consisting of about fifty of these cells will supply a current fully adequate to all therapeutic purposes, and answers admirably for office work of all kinds. The battery cells may be conveniently placed upon shelves in the cellar and connections made to the desired apartment. The cells should be arranged in series; that is, the zinc element of one cells connected to the carbon of the next, and so on throughout the number. The wires from the carbon of the first and the zinc of the last should terminate in the operating-room with a binding screw, and to these should be attached the cords of the electrodes when in use.

Electrodes.—An electrode is an instrument by means of which

a dose of electricity may be administered to the patient. The variety is limited only by the imagination or ingenuity of the inventor. A style much used in electro-diagnosis is shown in Fig. 19, and is called an interrupting electrode. *A* is a copper

FIG. 19.

plate surface which, when covered with absorbent cotton, is to be applied to the surface of the skin; *C*, a binding screw for the attachment of the conducting cord; *D* is the interrupter; *D C* is a copper wire; the spring, *D*, when pressed down by the finger of the operator, comes in contact with the wire, thus closing the connection between the wires *C D* and *D A*, the point *D* on which the finger presses being surmounted by an insulating button. This supplies the operator with a most convenient mode of closing and opening the circuit. The electrodes may be of any size and adapted to different purposes.

Commutator.—It is necessary to the successful use of any battery in therapeutics that it should be supplied with an arrangement by means of which the current may be rapidly reversed; that is to say, if the patient holds in his right hand the electrode connected with the carbon plate, and the one connected with the zinc in his left, the current flows in through the right and out through the left. By means of a commutator this can be at once reversed, and the current made to flow in through the left and out through the right. The right, which, in the first instance, was the positive electrode, becomes by means of the commutator the negative electrode. The details illustrating the requirements of this arrangement will be enlarged upon later.

The importance of measuring the dose of electricity can scarcely be overestimated. No scientific application of this valuable agent can be made without it. Without it no record

of any value can be kept of previous treatment, for a battery giving one current strength to-day will probably give another to-morrow ; resistances will also vary. These variations render the old system of estimating current strength by the number of cells employed utterly unreliable. By means of the meter an accurate estimate of the amount of electricity used can be made and recorded for exact comparison.

The Current Controller.—By means of this excellent device the operator holds the electric current completely under his control. The minutest dose can be given, and it can be increased or diminished by almost imperceptible degrees. Several styles of current controllers or rheostats are in use. One of the best, if not the best, is that devised by Dr. G. Betton Massey, who describes it in "*Electricity in the Diseases of Women.*"

Fig. 20.

Massey's Current Controller.

"It consists of a ground-glass plate, provided with a tapering area of soft pencil-mark, broadening into thick graphite, imbedded in the glass, which is joined to lead. These act as

resisting materials, over which a brass contact attached to a crank can be made to pass. When the crank is placed to the right of the hard-rubber button the contact rests entirely on the glass, and the circuit is broken; moving it slightly in the direction of the arrow, it soon touches the graphite mark and permits the least amount of current to pass through, since the current must pass through the whole length of the graphite, a fairly conducting medium. As the crank is slowly brought down from the point of rest and up the other side, there is a progressive gradual increase of current, until finally the thick graphite and the lead at the left of the rubber button is reached, when the whole power of the battery is turned on, there being no resistance remaining in the controller. A reverse action turns the current off. If this motion is made slowly, the increase and decrease is exceedingly gradual. The screw is for breaking the circuit, and should be screwed *in* when using the instrument. Special attention should be paid to the following points in order to prevent mishaps and to retain the full working capacity of the controller:—

"1. Always place the turning crank to the right of the rubber button before applying the electrodes to the patient, so as to be sure that the full resistance is interposed, otherwise an unpleasant or even dangerous shock to the patient might result.

"2. After the electrodes are in place, turn the crank down and toward the left *slowly* until the meter shows the desired strength of current.

"3. If using an incandescent current, never bring the metallic part of the cords or electrodes together unless the crank is well over to the right.

"4. Prevent all dust from settling on the glass plate.

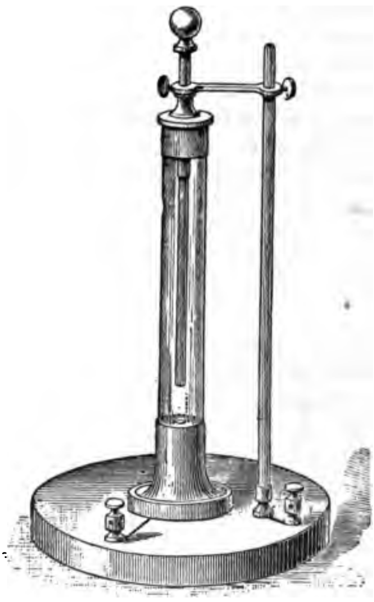
"5. Renew the graphite covering on the glass plate as often as marks of wear are visible by rubbing graphite over the circumscribed area from a *very soft pencil.*

"This instrument is chiefly valuable in enabling us to use an incandescent-electric light current for all strengths of medico-galvanic needs."

Water Rheostat.—This is an arrangement by which the electrical current is passed through water by means of a movable

conducting rod; the stretch of water through which the current flows is increased or diminished, a long stretch of water, of course, offering greater resistance, and thereby resulting in a weaker current than a short stretch. By inserting or withdrawing the rod the current strength may be very gradually increased or diminished.

FIG. 21.



Water Rheostat.

The conducting wires from the battery should be located in a convenient part of the apartment, and the current controller attached thereto; from the controller the current should pass to the milliampere meter, and thence to the object of treatment.

Several objections may be noted as applying to the employment of one-fluid cells.

1. The acid solution, by its continued action upon the elements, becomes constantly more and more dilute, and as a result evinces a progressive loss of power.

2. As the solution increases in dilution the internal resistance of the cell also increases, a saline or acid solution being a better conductor than pure water.

3. The action of the solution upon the positive plate results in an accumulation of deposit in some instances; thus, where sulphuric acid, zinc and copper are used, zinc is gradually deposited upon the copper plate, resulting in impairment of current strength, *i. e.*, the potential of the copper is increased, consequently the difference of potential is diminished, which signifies less electro-motive force.

Polarization is another cause of objection to the single-fluid cell; it means the collection of hydrogen upon the copper plate. Hydrogen being a poor conductor, its accumulation upon the copper would tend to decrease its conductivity, and as a direct consequence the electro-motive force is diminished, owing to the fact that copper has the same kind of potential to hydrogen that it has to the acid; therefore, the electro-motive force being the *difference of potential*, the difference of their *combined* potential and that of zinc would be less than the difference of potential of one of them and the potential of zinc. To avoid these objections the two-fluid cells may be used.

Faradism.

In 1832 Faraday discovered that electricity or an electric current could be produced in a conductor by the mere proximity of another conductor through which a galvanic current was flowing. To this he gave the name of induced electricity or currents of induction. The same effect is produced by the influence of magnets.

The peculiarity of the induced current is notable; *i. e.*, *it is only apparent at the moments of making or breaking the circuit in the conductor through which the galvanic or inducing current flows.*

To demonstrate this, let us assume a copper wire conductor, both ends of which are connected with a galvanometer; *i. e.*,

including the latter in a circuit; a similar wire connects the elements of an ordinary galvanic cell; if the latter be rapidly brought near to and parallel with the first conductor, the galvanometer will indicate an electrical current passing through it, but in a direction opposite to the flow of current in the other or inducing conductor. If now the conductors are permitted to remain stationary in this position, the galvanometer will show no evidence of a current continuously flowing through the wire with which it is connected; but if the wire attached to the galvanic cell be rapidly removed from its proximity to the former, the galvanometer will again *momentarily* indicate a current, and it will now be in a direction opposite to the first, or in the same direction as the current flowing through the conductor just removed.

From these observations we obtain the following very important facts:—

1. If a metallic conductor, through which a galvanic current is flowing, be rapidly brought near to and parallel with another metallic conductor, a current will be induced in the latter, but its direction will be opposite to that of the former.

2. If the conductors remain stationary and the current of constant strength, no such induced current will be observed to continue.

3. If the inducing conductor be removed from its position in proximity with the other conductor, a current will again be observed, but it will now flow in a direction opposite to the first—*i. e.*, in the same direction as the current in the inducing conductor.

4. If the current in the inducing conductor be of very decidedly decreasing strength, a direct current will be observed in the adjacent conductor.

5. If the current in the inducing conductor be of very decidedly increasing strength, a reverse current will be observed in the adjacent conductor.

6. If the circuit of the inducing conductor be broken, a momentary *direct* current will be observed in the adjacent conductor. If the circuit of the inducing conductor be closed, a

momentary *reverse* current will be observed in the adjacent conductor.

The "faradic" current *is* the *induced current.*

The faradic and galvanic currents are practically the only important ones in therapeutics. Some observers, however, of late have been attaching increased interest to static electricity. The current flowing through the conductor connected with the galvanic cell is called the *primary current;* the current induced thereby in an adjacent conductor is called the *secondary current.*

At each closure of the primary circuit a current is developed in the secondary circuit, momentary in duration and opposite in direction. At each opening of the primary circuit a current is developed in the secondary circuit, momentary in duration and in the same direction. Instead of straight parallel conductors, coils of insulated wire, one within the other, may be used; a current passing through one inducing a current in the other.

Generally the inner coil is connected with the galvanic cells, thus forming the *primary coil*, and should consist of a comparatively small number of turns of a thoroughly insulated, rather large, copper wire.

The *secondary coil* should be made to slide over and completely encircle the primary coil, but at no point to come in contact therewith. It should have many more turns than the primary coil, and the wire should be much finer. It also must be well insulated.

The primary coil, when encircled by the secondary, is practically parallel thereto. Opening or closing, the primary circuit will be followed by an induced current in the secondary coil, governed by the statements above made. If the opening and closing of the primary current occur quickly and continuously, they will be followed by a recurrence of rapidly alternating currents in the secondary coil. It is by this method almost exclusively that the faradic current is utilized in medicine. The strength of current in the secondary coil is proportionate to the number of turns in the primary coil, multiplied by the number of turns in the secondary.

Ruhmkorff's Coil.—This apparatus was constructed for the

purpose of producing induced currents by means of alternately opening and closing in rapid succession the primary circuit.

The primary coil is cylindrical in shape and hollow, for the reception of a soft iron bar or bundle of iron wires ; the secondary coil, also cylindrical in shape, is hollow for the reception of the primary coil and iron contents. The primary coil is connected with the poles of a battery, and the current therefrom, alternately opened and closed, by means of an automatic appliance, whereby a current is induced in the secondary coil. The wires should be well insulated, and to attain that end great care is observed. The primary wire, about four times greater in diameter than the secondary, is coiled first on a cylinder of cardboard and surrounded by one of glass or other good insulating material ; upon this is coiled the secondary wire. Not only should the wire be carefully insulated, by means of a silk covering, but each separate layer of coil well coated with melted shellac. The potential of the induced current varies with the length and diameter of the wire.

Armament for Rapid Interruption.—By this contrivance the circuit of the primary current is completed by a hammer-tipped spring capable of vibrating, resting upon a plate called the anvil, and subject to the influence of the soft-iron bar within the coil. When the circuit is made, the bar becomes a magnet, attracting the hammer to itself, thus drawing it away from its resting-place upon the anvil. This immediately breaks the circuit, the bar is demagnetized, the hammer is released, and again assumes its original position resting upon the anvil. This instantly restores the circuit, and the process is repeated. So rapidly is the current made and broken by this means that the vibrations of the spring hammer produce a sustained musical note. The strength of current in the secondary coil depends largely upon the number of turns in the wire which surrounds the primary coil. If the coils are so arranged that the secondary may gradually be drawn around the primary coil, the induced current will be found to increase gradually in proportion to the distance traversed by the secondary coil in surrounding the primary, and *vice versa.* The induced current will decrease proportionately as the secondary coil is withdrawn from the position

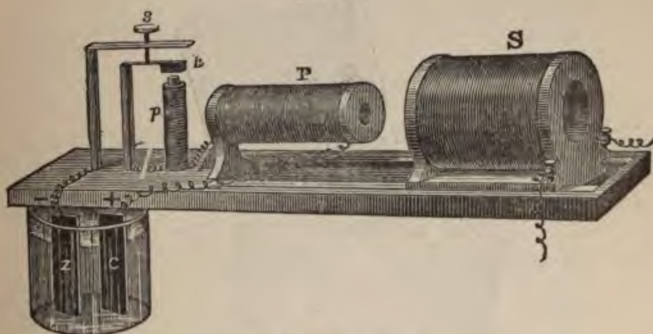
encircling the primary, until finally a large diminution occurs suddenly, when the primary coil is entirely unencircled by the secondary, and the two coils stand end to end. This phenomenon is much utilized in the construction of faradic batteries, for the purpose of increasing and diminishing the current.

The same object may be accomplished with perhaps equal facility by means of a metallic cylinder of sufficient diameter to allow of its being inserted between the soft-iron bar and the coil. The current can be readily controlled by simply inserting and withdrawing the cylinder. This phenomenon is of course due to the fact that the metal intervening between the primary current and the iron bar prevents the lines of force from acting upon it. When the cylinder extends over the entire surface of the iron bar very little magnetism occurs, and the coil becomes one without a core. The magnetic core intensifies the current.

Batteries.

One of the best is Otto Flemming's make of the Du Bois Reymond battery.

Fig. 22.



Du Bois Reymond.

The secondary coil is supplied with an appliance by means of which it may be propelled over the primary coil. It is also provided with a double scale and a pendulum; by means of the

Fig. 23.

Portable Battery.

Fig. 24.

Portable Battery.

Fig. 25.

Galvanic Portable Battery.

Fig. 26.

Cabinet Battery.

latter a slowly interrupted current may be used. It is not portable, and for that reason is suitable chiefly for office and hospital work. (See Fig. 28.)

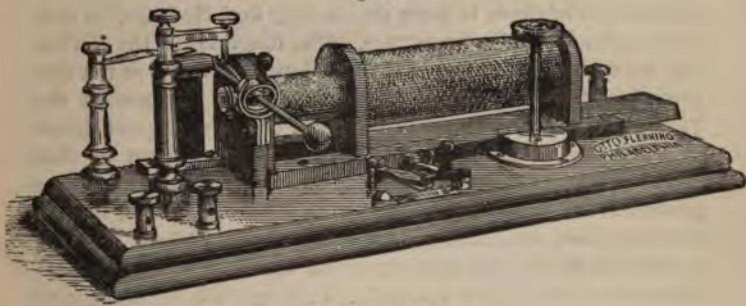
Any cell of high electro-motive force and little internal resist-

Fig. 27.

Cabinet Battery.

ance may be used to furnish the primary current of a faradic battery. It should admit easily of being cleaned and replen-

Fig. 28.



Slow Interrupter.

ished ; it should have an arrangement by means of which the elements can be withdrawn from the fluid when not in use. The current resulting from the pendulum or slow interrupter differs somewhat in its character from the quick interrupter. When the latter is used the current is reversed so rapidly that there exists practically no choice of pole. The current associated with the slow interrupter, however, approximates in character the galvanic, and we have actually a cathodic followed by an anodic effect at each interruption. Figs. 26 and 27 combine the galvanic with the faradic ; either may be employed at will.

Franklinic or Static Electricity.

This, as a science, may be said to treat of peculiar phenomena exhibited by bodies when subjected to certain mechanical forces, and of the results of these phenomena.

As a physical agent it is capable of developing immense power, exhibiting itself chiefly by the properties of attraction and repulsion.

Statical electricity is electricity in a state of rest, and is commonly developed by means of friction, being sometimes called frictional electricity. Before the Christian era it was known that amber when rubbed with silk assumed certain properties,

latter a slowly interrupted current
portable, and for that reason is
hospital work. (See Fig. 28.)

Any cell of high electro-motive

Fig. 27.

Cabinet battery.

such as that of attracting light bodies. Thales of Miletus asserts that this power was due to the presence of a soul in the amber which when under the influence of excitement left it and returned with the light bodies. Tourmaline is the substance we suppose the ancients to have meant by "*lapis lincurius*," a substance possessing like properties. The functions of the électric fish were also known, but that any relation existed was not suspected by the early philosophers. But little advance in the knowledge of this subject can be traced until the reign of Queen Elizabeth of England is reached, when Dr. Gilbert of that country showed by a series of experiments that amber did not alone possess these characteristics, but that other substances, such as sulphur, glass, etc., claimed a share. To Dr. Gilbert, perhaps, as much as to any one, may the credit belong of having founded this science, crude, few and isolated though the facts were at that early day.

The common experiment of rubbing a rod of glass with a fragment of dry silk and the property it thereby develops of attracting small pieces of paper, etc., is known to every schoolboy; likewise the fact of the paper after remaining in contact for a certain length of time with the rod, suddenly seeming to be repelled and flying off.

For many years it was supposed that only certain substances possessed the quality of becoming electrically excited and they were called electrics, all other bodies being named non-electrics. Now, however, it is known that the "*electrics*" were simply non-conductors, consequently the "*non-electric*" are conductors. Conductors, when carefully insulated, readily develop the qualities of non-conductors, hence under certain circumstances all bodies are electrics. The classification into conductors and non-conductors is practically correct, so great is the difference of bodies in this respect. Dry gas is, perhaps, the only perfect non-conductor.

When a scrap of paper, after having been attracted by the excited glass rod, drops off, it is said to have become *electrified*.

If an insulated conductor, having been electrically excited, be placed in contact with a *similar* conductor, it will be found to lose a portion of its electricity and both conductors will *be equally electrified*. If the electrified body be very large in

proportion to the other, but little of its electricity disappears; if, on the contrary, it be small compared with the other body, much of its electricity will be lost; while if the difference be infinite or very great, as in the case of the earth, all evidences of electrical excitement will be seen to disappear from the smaller body.

Poor conductors are utilized to *insulate* good conductors, and dry air is one of the *best of insulators*. When air becomes moist it is much improved as a conductor hence experiments, etc.; with frictional electricity are best carried on in dry weather.

Conductors and Non-conductors.

When a rod of glass is thoroughly dried and briskly rubbed at one extremity with dry silk the portion subjected to friction will be found by means of the electroscope to be electrified, and the other portion unchanged. This fact applies not only to glass, but to many other substances, such as shellac, sealing-wax, etc. But a rod of metal subjected to the same treatment will be equally electrified over its *entire surface*. From this experiment it is evident that we have in nature *good* and *bad* conductors of electricity, just as we have good and bad conductors of heat. An important application of this principle consists in utilizing the poor conductors to insulate good ones. The conductivity of bodies is entirely relative and really constitutes the quality treated of in the article on galvanism under the head of Resistance. The best conductor of electricity is *not perfect*, and the worst does not *entirely insulate*.

The following substances compose a list of electric conductors, the best being named first and the others following in order of merit:—

All metals,
Well-burned charcoal,
Plumbago,
Concentrated acids,
Dilute acids,
Saline solutions,
Spring water,
Rain water,
Snow,
Living vegetables,
Flax,
Hemp,
Living animals,
Flame,
Moist earth and stones.

The following are non-conductors, in order of non-conductivity :—

Shellac,	Wool,
Amber,	Feathers,
Resin,	Dry paper,
Sulphur,	Leather,
Wax,	Baked wool,
Jet,	Porcelain,
Glass,	Marble,
Mica,	Camphor,
Diamonds,	Caoutchouc,
Ebonite,	Chalk,
Gutta percha,	Oils,
Silk,	Metallic oxides.

No perfect insulating substance is known ; electricity will sooner or later escape by means of the insulating supporters and seek its common reservoir, the earth. Glass is quite commonly used as an insulator, but the moisture which accumulates upon it offers a passage to the electricity which is eventually traversed. It may here be noted that glass can be much improved as an insulator by a coating of shellac.

Two Kinds of Electricity.

It has long been known that different bodies seem to develop different qualities when electrically excited. For instance, a glass rod, after being electrified by means of rubbing with silk, if approached to and brought in contact with a pith ball suspended by a silk thread, the ball will, as we have seen above, at first be attracted only to be afterwards repelled ; the latter being now *electrified* will continue to be repelled by the glass rod so long as they both retain their electricity, but if a stick of sealing-wax (electrified) be brought toward the ball immediately after it has been repelled by the glass, the former will be attracted thereby more strongly than at first it was attracted by the glass. Different explanations have been advanced to account for this phenomenon, among them the theory of two

fluids, but so far as absolute knowledge is concerned we are perhaps as far from enlightenment as the ancients.

Theory of Fluids.

Franklin supported the theory of a subtle indefinable fluid pervading every substance and capable of a peculiar repulsive action upon its own particles, each substance possessing a quantity peculiar to itself in its natural condition. By means of friction this quantity increases in some substances, and is said to be positively electrified. By the same means other substances lose a portion, and are said to be negatively electrified thereby.

Positive electricity attracts negative and repels positive. **Negative electricity attracts** positive and repels negative.

The kind of electricity which may be developed upon a body depends not only upon the substance of the body itself, but upon the substance of the body with which the friction is applied. For example, commonly glass assumes positive electricity, but if it be rubbed with the fur of a cat negative electrification will result. The character of the surface is also of much moment. A piece of rough glass rubbed with a smooth piece of the same will result in the former developing negative and the latter positive electricity. Silk ribbon rubbed together will result in negative electricity being developed upon the piece transversely rubbed, and positive upon the piece rubbed *with its grain*. Also, if portions of the same substance having similar surfaces, but being of a different temperature, be rubbed together, negative electricity will result upon the warmer. Color, also, governs the kind of electricity in some instances; thus, a piece of black silk rubbed with white will assume negative electricity, while the latter acquires positive.

Other Methods of Generating Electricity by Means of Mechanical Force.

Some minerals, when pressed between the fingers, develop electricity; for instance, topaz, fluor-spar, and calc-spar. Tearing apart striæ or laminæ, as of minerals, cardboard, etc., will

produce the phenomenon, as will also vibrations. Other methods not necessary to detail here produce the same results.

It is interesting to note that when two bodies are rubbed together two kinds of electricity are developed at the same moment, the one being positive and the other negative in an equal degree.

Electrical Induction.

It can be demonstrated by a well-known experiment that a *positively* electrified globe, supported upon an insulator, will electrify a neighboring cylinder (also insulated), even though they be not in contact, the cylinder previously having been neutral. It can also be shown that the portion of the cylinder nearest to the globe will exhibit negative, and the most remote extremity positive electricity. The ends of the cylinder will acquire the greatest electrification, and this will diminish towards the middle until a point is reached where no electricity exists. If the globe be removed to a great distance from the cylinder, the latter will again assume its previous unelectrified condition. This phenomenon is entirely analogous to the facts already set forth and observed in regard to galvanic induction, and is probably caused by the separation and induction of the combined electricity upon the cylinder. If, now, while the globe is near the cylinder the latter be connected with the earth, the positive electricity will flow thereto and an equal quantity of negative electricity will take its place upon the cylinder, and by means of the force of attraction exerted upon it by the positively electrified globe will increase the negative charge upon the end near it. Then, if the connection with the earth be broken and the globe removed, the cylinder will be found to be negatively electrified and the whole cylinder will be equally charged. This is sought to be explained upon the same theory as the polarization of molecules in the galvanic cell, the molecules of the air being the intervening medium. By careful experimentation Coulomb demonstrated the two following laws :—

1. Two electrified bodies attract and repel each other with a force which varies inversely as the square of their distance.

2. Two electrified bodies remaining at a constant distance

from each other, repel and attract each other with a force which varies directly with the product of the quantities of electricity with which they are charged.

It is also established that the electricity of a body occupies the surface only, and is kept in that position by means of the resistance offered by the air to its escape, and is driven from the centre by its own self-repulsive force. This fact would naturally lead to the conclusion that a hollow wire would at least be equally serviceable as a conductor of a galvanic current, but the relation is not borne out, for in the case of currents the capacity depends upon the cross section of the conductor, a fact important to bear in mind. A hollow wire is *not* so good a conductor as a solid one.

The first frictional electrical machine was invented by Von Guericke, the constructor of the first air-pump. Improvements

Fig. 29.

were subsequently added by Hawksbee, Winckler, and Ramsden. In the first machine the hand was used as the source of friction, imparting negative electricity to a globe of sulphur revolving on an axis, the positive flowing through the body to the earth.

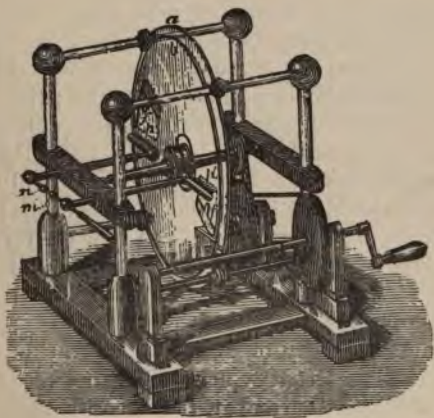
A modern modification of Ramsden's machine is shown in Fig. 29. It consists of a glass plate and two pair of rubbers made of leather stuffed with horse-hair, and coated with bisulphide of tin; they produce the friction and are connected with the earth by means of a chain. The reservoirs consist of two cylinders of metal, hollow, and supported by glass pillars, their ends being globular. From the end near the glass plate projects a curved U-shaped rod, armed with points to facilitate the reception of electricity from the plate—the points, or comb, extending to both sides of the plate, as in Figure 29; the other ends of the cylinders are connected by a rod of metal, from the centre of which projects a short additional rod, terminating in a knob for the discharge of the electric spark. A brief explanation of the phenomena exhibited by this machine is as follows: When the glass plate is revolved the friction of the leather rubber upon it decomposes the electricity, the positive seeking the glass, the negative the rubber; the positive electricity upon the glass plate as it approaches the brass comb is attracted thereby, and passes thence to the cylindrical reservoir, which is called the *prime conductor;* negative electricity passing from the comb in return is carried by the glass plate to the rubbers; these being connected with the earth receive positive electricity, which is attracted strongly by the negative they already contain. But this union is only made to be again immediately disrupted by friction, the positive electricity flowing to the prime conductor, and thus reinforcing the charge there contained, until, finally, the tension becomes so high that it is discharged in sparks with a characteristic sound.

The Holtz Machine.

Many forms of electrical machines have been constructed. Some are charged by friction and some by induction. The Holtz machine, perhaps the best known of all, is of the latter form, and develops great power. It was invented in the year 1865, in Berlin. Uncomplicated, this machine consists of two glass disks, varnished, one of which is made to revolve, the other remaining stationary. The stationary disk contains two

openings, through each of which passes a paper strip with pointed end, the base of each strip being fastened to the plate above the opening; they are called the inductors. The plates are close to and parallel with each other; opposite to the open-

Fig. 30.



ings, but on the other side of the revolving plate, is placed a pair of metal combs, joined by conductors to the poles; the revolving plate is made somewhat smaller than the stationary one, and the paper points project in an opposite direction to the motion of the revolving plate; the latter has no openings. The combs are connected with insulated conductors, which are so arranged that they may be approximated to each other; they terminate in knobs to facilitate the discharge of sparks.

To operate the machine the knobs of the conductors are brought together, and one of the paper armatures electrified by bringing in contact with it, for instance, a negatively-electrified body; the glass plate revolving, both armatures become electrified, one with negative the other with positive electricity. The first armature being negatively charged tends to repel similar electricity near it and attract the opposite; hence, negative electricity will depart from the face of the revolving plate near

the armature to the metallic comb placed there to receive it, while from the comb-points will flow to the plate positive electricity; the other (second) comb, of course, also becomes negative, as it is in connection with the first, as above mentioned; thus, the glass plate passes from the first comb to the second positively electrified. Upon reaching that point the second comb discharges upon it negative electricity, and receives from it positive in return, and so the second armature also becomes positively electrified by the discharge through its points of negative and reception of positive electricity; the plate passes on to the first armature negatively electrified, hence the first comb will discharge positive electricity upon the plate, the latter giving negative in return; the armature will also attract more negative electricity from the other side of the plate, owing to its having a higher tension. Each time the revolving plate passes the first comb it has imparted to it an additional supply of positive electricity; the same thing follows in relation to the second armature; hence, both armatures become charged with opposite electricity of constantly increasing tension. A current of positive electricity flows from the second to the first comb, and a negative current in the opposite direction. Upon separation of the knobs electricity will leap from one to the other. The working of the machine requires that every portion of the revolving plate must be charged with a different kind of electricity from that of the armature it leaves, and with the same kind as that possessed by the armature it is nearing. To accomplish this the conductors must be near enough to each other for communication. The Holtz machine is extremely sensitive to moisture, and works best in a very dry room. The original machine has been improved by various additions, suggested by different observers.

Effects Produced by Induction Machine.

The two rubbers of Ramsden's machine being connected by means of metallic conductors with the earth, and the insulators and plates having been well dried with a warm cloth, the plate is rapidly revolved, and the machine is in operation. If a finger is presented to the prime conductor for a short space of time,

a spark will be the result, accompanied by a sharp stinging sensation in the part presented ; this is the result of induction, the finger possessing induced negative electricity, as a result of positive electricity contained by the prime conductor, the tension increasing until the resistance of the air is overcome, when the spark occurs. In a darkened room the latter is plainly visible. By employing a hollow-metal conductor of globular shape, with a well-insulated handle, long sparks may be obtained, because a greater quantity of negative electricity may be thus accumulated. Through a short distance the spark will take a straight course ; through a long distance a zigzag course, resembling lightning. Under favorable circumstances, *i. e.*, dry air, etc., the machine will emit a peculiar hissing sound, and bright, luminous so-called brushes may be seen issuing from points of the conductor. When the electricity is not otherwise conducted away, bright sparks frequently fly across the plate between the conductor and the rubbers. It has been observed that positive electricity affords larger brushes than negative. If a person be placed upon a platform supported by glass feet, *i. e.*, insulated, and connected with the prime conductor, he will become electrified, and sparks may be obtained from any portion of the body, even through the clothing ; the resistance offered causes the spark to emit a distinct report, together with a stinging sensation. The hair of the subject, if of the proper length, will stand on end and separate. If a point be made to terminate a portion of the conductor, as in

FIG. 31,

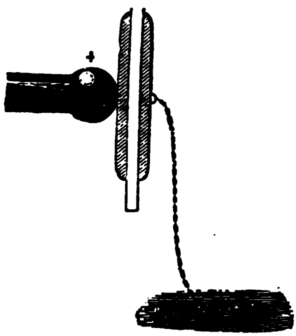
Candle with flame deflected.

the electricity will create a distinct breeze or current of air, easily distinguished upon the open palm, and well illustrated by the figure, which shows the flame of a lighted candle swept from its natural course by the current. The discharge of electric sparks also decomposes the atmosphere forming ozone, which is readily recognized by its odor.

The Leyden Jar.

Electricity may be condensed until extremely large charges accumulate. This is accomplished by means of two conductors, separated by a glass plate or non-conductor, one of the conductors being connected with the earth, the other with the prime conductor of a machine, as in Fig. 31; the conductor

FIG. 32.



in contact with the machine becomes charged with one kind of electricity, while the other becomes charged with the opposite kind, which is held in position and drawn from the earth by the power of the glass plate or dielectric. It is upon this principle that the Leyden jar is constructed; a glass jar is coated or lined both inside and outside with tinfoil, sufficient space being left uncoated above to prevent union of the opposite charges taking place; the mouth is closed with a well-baked wooden cover, perforated by a rod suspending a metallic chain, which extends

to the bottom, thereby connecting the rod with the inner lining of the jar. The upper or external extremity of the rod consists of a knob, by means of which connection may be readily made between the inner and outer coats, the common means of communication being a jointed discharger with an insulating handle. To charge the Leyden jar, one of the coatings should be connected with the prime conductor of the ordinary electric machine, and the other with the earth, it being immaterial which. If the Holtz machine be in use, it is evident that one conductor should connect with the inner coating of the jar, the other with the outer. A battery of Leyden jars can be constructed by arranging several jars upon a sheet of any good conducting metal, and connecting all the inner coatings by means of chains or rods extending from one knob to another. It may be charged by connecting one jar with a machine, as above directed. The usefulness of the Leyden jar is best displayed where great intensity is desired, its

Fig. 33.

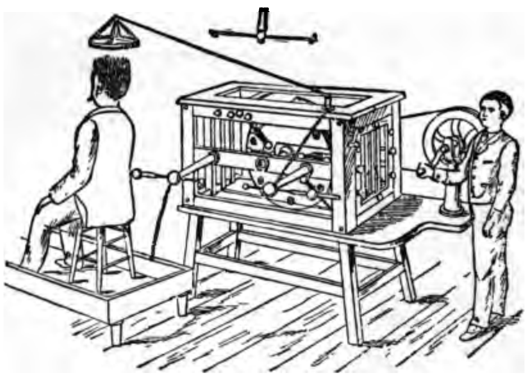
Fig. 34.

Patient being treated with Static.

capacity depending upon, within limits of course, the thickness of the glass, the intensity increasing with the thinness of the

glass, and upon the size of the jar and the extent of surface coated. The Leyden jar may be discharged by bringing the outer and inner coatings into connection with a conductor. Combustible matters may be consumed by means of the Leyden jar, and a fine metallic wire may be heated and even fused thereby. After discharge and a short interval of rest, one or two additional, though diminished, discharges may be obtained, and are called the residual charges. Lightning and the discharge of the Leyden jar possess the same characteristics—even a small jar communicating a very perceptible shock to a subject, a large one being capable of producing death.

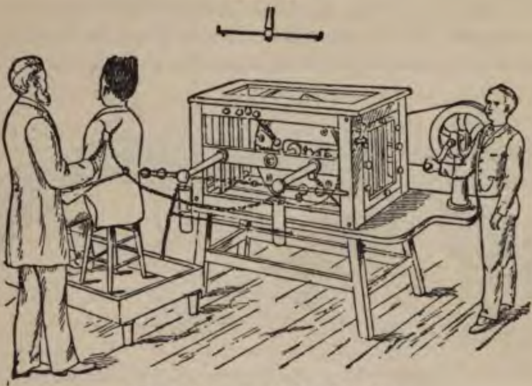
FIG. 35.



Patient being treated with Static.

Morton, of New York City, writes concerning a "new system of therapeutic administration of static electricity." By means of certain ingenious apparatus he claims to transform the old spark effect of the influence machine into a current capable of most, if not all, of the uses formerly supposed to be possessed by the galvanic and faradic currents only. The application may be made by means of moistened sponge or cotton electrodes, precisely similar to those already described in a previous page. The spark feature is not abolished entirely,

FIG. 36.



Patient being treated with Static.

FIG. 37.

Patient being treated with Static.

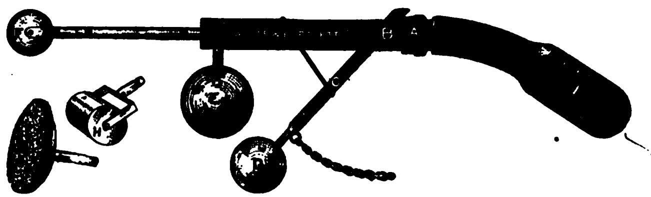
but is arranged to occur at a distance from the subject under treatment, but of course forms part of the circuit with the patient. The electrode, which the author calls the static universal electrode, is represented in Fig. 38.

The spark occurs between the two balls; the latter may be separated or approximated by means of a trigger.

The advantages claimed for this method are strong contractions of muscles with little pain; while the motor filaments are

excited, the sense of pain seems abolished. Morton claims that in this relation it may prove a valuable substitute for ordinary massage. If further research confirms this view, it would amply reward the investigator, massage as a factor in modern

FIG. 38.



treatment having assumed such pre-eminent importance in its proper sphere. In this connection the author claims that no form of electricity acts as a "more energetic" stimulus to nerve and muscle than this. If this can be demonstrated, considerable advance has been made, nerve and muscle irritability being of course different in character.

"*The second prominent characteristic*" is its power of alleviating pain, the author claiming a "specific analgesic quality for the current" entirely separate from its influence upon the circulation and lymphatics; sciatica, ovarian pain, and the pain due to tonsillitis acuta, are, he states, quickly subdued. In this respect he believes his system will prove decidedly more efficacious than either faradism or galvanism; the latter, however, he concludes, may, in certain cases, succeed in relieving pain where the "new system fails," owing to its superior electrotonic, polar, and electrolytic qualities. The author advances a theory by way of accounting for the analgesic effects of his system, in which the results are attributed to a vibration set up in the sensory nerve-filaments, whereby the power of transmitting impressions is suspended, the alternations of this current being extremely rapid. The author also hopes at a future time to be able to show that this current is capable of penetrating quite as deeply into the human tissues as the galvanic—perhaps more deeply.

Dr. Morton has named his discovery "The Franklinic interrupted current."

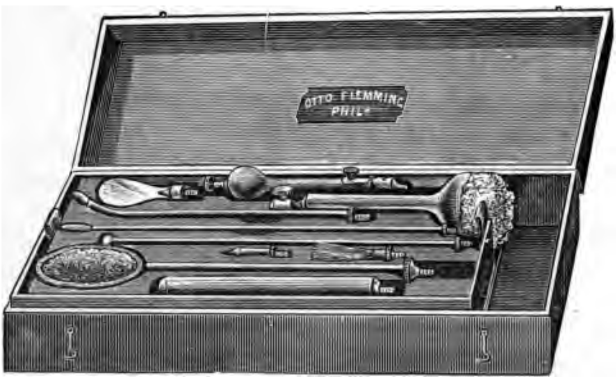
Many different methods may be employed in the treatment of diseases by static electricity, a great advantage being claimed in that the patient need not disrobe. One earnest advocate of its value as a therapeutic agent writes of having relieved a female patient from the suffering induced by a bunion—he *drew* a spark (not the bunion) through the shoe.

The Physiological Effects of Electricity.

Having now given within certain limits an extremely condensed and, we trust, simplified outline of electricity as it exists and is generated, we pass on to the important subject of its physiological bearing and application to medical diagnosis and treatment. We have not made even an attempt to discuss theories or mathematical demonstrations; the scope of this little work being simply to lay before the average medical student and practitioner, unacquainted with the more advanced physics, sufficient knowledge of the subject to construct a battery and use it intelligently, both in treatment and diagnosis. First in order of importance the physician's equipment should be discussed; but it will be more convenient to describe the instruments in detail in connection with their application. In a general way, a physician should be supplied with a galvanic battery of a sufficient number of cells, fifty Le Clanche cells or modifications thereof answering every ordinary purpose. These should terminate in binding screws, located in a convenient part of the office for the attachment of reophores—*i. e.*, insulated copper-wire cords or conductors, by means of which the current may be conveyed through a current controller, thence by additional cords through a milliampere meter; from the meter reophores should conduct the current to electrodes, by means of which doses may be administered. The chief qualities of a battery, as stated previously, are convenience and cheapness. The requisite of being able to bring into use any stated number of the battery cells is, to a very great extent, obviated by the use of the current controller. All the cells may be in circuit, yet only a certain quantity of cur-

water, because salt renders the fluid more conductive, and without moisture the epidermis is an extremely poor conductor. Warm water is a better conductor than cold, and is also much more agreeable to the feelings of the patient. Erb, however,

Fig. 40.



Various Electrodes.

remarks that he has long discontinued the use of salt, owing to its causation of more marked burning of the skin, production of stains upon clothing, and destruction of electrodes by electrolysis.

Special electrodes for special purposes will be required, among which may be mentioned the faradic brush, often an extremely effective agent, and electrodes applicable to diseases of the rectum, uterus, pharynx, larynx, bladder, and, in fact, of most of the organs of the human body.

The field of usefulness occupied by electro-therapeutics extends over the ground of both treatment and diagnosis. In the latter it may, indeed, with safety claim infallibility within certain limits.

For the purpose of treatment the human body may be looked upon as a conductor, subject to all the laws bearing upon the distribution of the current through a conducting mass.

Organic tissues are poor conductors and may be looked upon as saline solutions, which vary in amount of dilution, supplied

from positive to negative instantly. It is equally important that the commutator should not only be capable of reversing the current, but also of rendering the circuit closed or open as desired.

The galvanometer, at first only recognized as a means by which the passage of a current could be known, is now useful in the form of a milliampere meter to measure the quantity of the current. It is absolutely necessary for exact scientific diagnosis and treatment.

The effect of a certain current strength differs with the size of the electrode.

The reophores should consist of well-insulated flexible copper wires about 2 mm. in length. They are commonly insulated by means of rubber covered with silk. The rubber protects them from moisture, which would interfere with perfect insulation. The connection between binding screw and reophore should be as thorough as possible.

Metallic electrodes are of unlimited variety and should be provided, when necessary, with insulated handles for the grasp of the operator. The applied portion should be covered with sponge, or preferably, owing to cleanliness and facility of renewal, with absorbent cotton moistened with a warm saline solution to promote conduction. This covering was suggested first by Massey of Philadelphia.

For precise localization, such as nerve-branches, motor points of muscle, etc., electrodes terminating in a small knob should be used. Erb denominates an electrode of this sort, the covering of which does not exceed ($\frac{1}{5}$ inch) $\frac{1}{2}$ ctm. in diameter, a "*fine*" electrode; one not exceeding ($\frac{4}{5}$ inch) 2 ctm., a "*small*" electrode; one of (2 inches) 5 ctm., "*medium*;" one not exceeding ($2\frac{1}{5}$ inches) 6 ctm. wide by ($4\frac{1}{5}$ inches) 12 ctm. long, "*large*." Electrodes of greater size than this are called by the same eminent authority "*very large*." These, he states, will rarely be required.

The electrodes should be readily adjustable by means of a screw to the handle, and a handle, such as previously described with interrupting arrangement, is often useful. The covering of electrodes should always be moistened with warm saline

patient to make a careful preliminary trial with the milliampere meter.

It has been observed by Erb that more resistance is offered to a current from scapular region across to scapular, with the electrodes nearly approximated, than from nape of neck to popliteal space—a point worthy of note. The depth of the cuticle is pretty much the same at all points, and as it is the surface extent chiefly that governs the resistance, the size of the electrode becomes an important factor. A certain density of current is necessary to produce desired therapeutical results. The density of a current may well be likened to the strands of a cord. If these are unwound and permitted to form a loose mass, they represent a current of little density, but if, on the other hand, the strands are tightly gathered together into a compact mass, or cord, they then represent a current of great density. The strands are the same in constituency and number in either case, but the results obtainable from them in their different conditions are far otherwise. Many more *strands* of electricity may be applied to a given space, if the current be of considerble density, than if the reverse obtains, and the effects will be proportionate. If the current of electricity enters the body from two ordinary electrodes, the number of threads of electricity depending upon the strength of current diverge from the electrodes and extend over the entire body. The greatest density, however, exists in the immediate neighborhood of the electrodes. If the electrodes are equal in size, the current will be of equal density at either pole; if not, the greater density will exist at the smaller electrode. Deeper in the body, the greatest density will naturally be found to exist in a straight line between the two electrodes. Of course, the density diminishes enormously almost immediately after penetration of the skin, the strands bellying out in their diffusion through the body. (Figs. 41 and 42.) All portions of the body are said to contain some threads of a current passing through any part of it, but outside of the zone of greatest density—*i. e.*, straight line between the electrodes—they are so few and unimportant as to become unworthy of consideration. A clear conception of this is necessary to the proper application of this force to thera-

peutics and the accomplishment of desired results. A glance at Figs. 41, 42, 43 and 44, will render the idea more simple. If

FIG. 41.

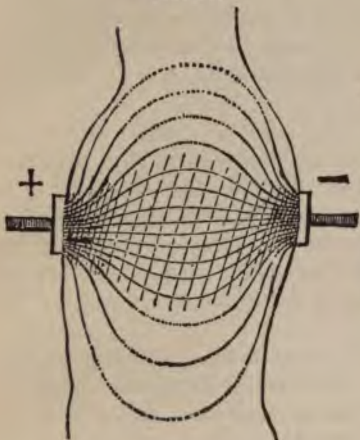


FIG. 42.

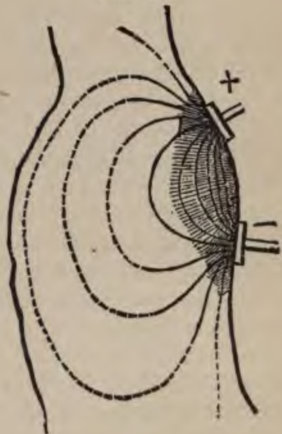


FIG. 43.

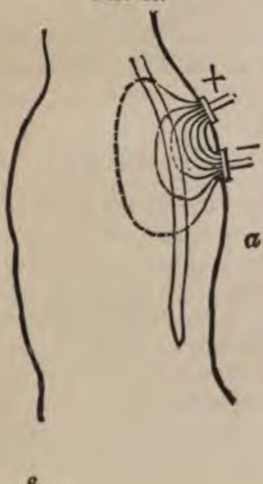
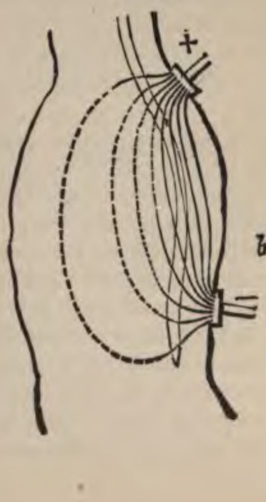


FIG. 44.



the part under treatment is deep-seated, the electrodes should be large and placed far apart, for the nearer the electrodes to each other, the greater the *proportion* between the threads of current of greatest density and those of least, the greatest density being superficial. If the part to be treated is of considerable, size and near the surface, two equal medium-sized electrodes should be used, applied close together, and in near proximity to the spot. (Fig. 43.)

If it is desired to treat a point near the surface with a current of certain density, two electrodes should be used, one quite small, the other as large as possible; the small one applied to the immediate vicinity, the large one as far distant as possible. The effect depends largely upon the difference in size of the electrodes; if one should prove so small that its resistance obstructs the current, it must be overcome by increasing the strength of the current.

For the treatment of any deep-seated organ the electrodes, as just stated, should be large and located far apart. A typical illustration may be cited in the treatment of the spinal cord, the object being to apply the electrodes in such a manner that the diseased part will, so far as possible, be situated in a straight line between the two electrodes. (Fig. 44.)

It has been observed by Helmholtz that the galvanic current disperses more effectively through deep-seated parts than the faradic. This fact is important.

Electrolytic Action of Electricity.

The physiological and therapeutic action of the currents can be better appreciated with some knowledge of this subject. Electrolysis is simply the decomposition of any substance by the galvanic current, the electrodes themselves remaining intact. This action was first demonstrated by Carlisle and Nicholson early in the present century by the decomposition of water. It has been found that a molecule contains two constituents, one electro-positive and the other electro-negative, and that when it is subjected to the action of the galvanic current one of them will be attracted to the cathode and the other to the anode.

Faraday named the negative electrode the *cathode* (written Ca.) and the positive the *anode* (written An.) or the descending and ascending currents respectively. The substance decomposed is called an *electrolyte* and its constituents are designated *ions*, the one attracted to the anode being an anion, the one attracted to the cathode a cathion. This phenomenon is due to a chemical change occurring at the points of entrance and departure of the galvanic current. In some cases gases are liberated at one or other of the electrodes, in others metals or solutions of them. When the electrodes of an ordinary galvanic battery consist of platinum plates and they are immersed in a vessel of water, if the battery be of sufficient power bubbles will soon appear upon both plates, oxygen constituting those upon the anode, hydrogen those upon the cathode. If a saline solution be substituted for the water, the alkaline element will be attracted by the cathode, the acid by the anode; in other words they will be set free at the above-named poles. A substance must exist in solution in order to be susceptible to decomposition by electrolysis, so that the molecules may be readily separated. Assuming the platinum electrodes to be immersed in a solution of copper sulphate, we would find that the plate through which the current enters the fluid remains unchanged while the plate through which the current departs is coated with a deposit of copper. The copper in the solution would be found upon examination to be diminished by a quantity precisely equal to the amount found upon the electrode. This is simply an illustration of a very general law that in similar cases the plate through which the galvanic current departs, and that plate only, is the recipient of deposit, and the amount of deposit is in direct proportion to the strength of current of electricity.

It is a fact worthy of mention, though perhaps of no peculiar importance to the therapeutist, that not only a separation of the molecular constituents takes place but also a movement of each to its proper pole. Davy demonstrated this years ago by means of a solution of sodium sulphate contained in two vessels and connected by a bundle of asbestos previously well moistened in the solution. Into one vessel was immersed the positive and into the other the negative pole of a galvanic battery. After a

time he found that one vessel contained the sulphuric acid and the other the sodium. The same phenomena will occur if the two vessels contain any number of different saline solutions, all of the metallic bases occupying the vessel in which the negative pole is immersed, and all the acid radicals the other. This will take place through any number of similarly connected vessels, limited only by the accumulated resistance, if all the resulting compounds of molecules are soluble; but if, in any one of the vessels, molecules combine to form an insoluble compound, it will simply be precipitated and thus cease to form part of the solution.

It should be observed that in electrolytic as in all other electrical phenomena, like attacks unlike, the electro-negatives going to the anode and the electro-positives to the cathode.

Electrolysis also occurs in the human body, *i. e.*, animal tissues. The galvanic current possesses decidedly the greatest amount of electrolytic power, so much so indeed that the faradic and static currents may in this connection be overlooked. This is explained by the fact that the induced current is so momentary in duration.

Cataphoresis.

This is a purely mechanical effect of the galvanic current, and is simply electrical osmosis. It is necessary that the student should have at least an outline of its action, for experiments tend to show that medication may, to some extent, be facilitated by its use. The direction of the osmotic action is with the current, but *solid* particles suspended in the solution have been observed to take an opposite course. It is of evident importance to hold this peculiar phenomenon of electricity in mind as further developments are being sought.

Effect Upon Nerve.

Any worker in the physiological laboratory can without difficulty study and verify the unvarying effects of the agent under *discussion upon the nervous system.*

An electrode, through which a galvanic or faradic current is flowing, applied to a normal motor nerve will result in the contraction of the muscles supplied by that nerve, provided the current be sufficiently strong and interruptions made.

This effect of the galvanic current occurs practically only at the *moments* of closure and opening of the circuit. A gradual increase or decrease of the current strength will cause no muscular contraction, but a sufficient increase of current made suddenly or a similar decrease of the same will produce this result. Therefore a galvanic current applied to a motor nerve will produce no muscular contractions if constant or very gradually increased or diminished even if it be increased to great strength. *The galvanic current is effective in causing muscular contractions only at the moment of opening and closing the circuit.*

The faradic current also causes contractions of the muscles supplied by the nerve stimulated, the contractions being stronger following the opening than the closing current; but if the currents succeed each other with the rapidity of ordinary batteries employing the rapid interrupter, no distinction is possible, and the muscles assume a continuous tetanoid contracture. Much labor has been devoted to the subject "of muscular contractions caused by electricity," and very accurate and definite results have been achieved. The same may be said as to its action upon nerves. In order to test the effect of thus "stimulating" motor nerves, one electrode should be placed upon the *isolated* nerve, the other upon an *indifferent* point, *e. g.*, the sternum or spine. A sufficiently strong galvanic current will, as we have seen, cause contractions of the muscles controlled by the nerve *if both be in a normal condition.* The important point, however, to remember is that under these circumstances both poles do not possess equally the power of producing this effect: *the cathode is stronger than the anode;* that is to say, the weakest current capable of inducing the slightest contraction with the cathode in place will cause *no* contraction whatever with the anode in place. This above-mentioned contraction occurs upon *closing* the circuit. The result is written thus: Ca. Cl. C., *i. e.*, cathodic closing contraction. If the poles be now reversed, making the anode active, the current being increased to a certain point,

a contraction will occur upon opening the circuit: Ca. Cl. C. being also obtained, and stronger than before. The second contraction is called anodic opening contraction, and is written An. O. C. (This contraction occurring in this sequence refers only to galvanic stimulation as applied to the isolated nerve *direct;* when applied to the muscle tissue as ordinarily practised, anodic closing contraction (An. Cl. C.) follows Ca. Cl. C.) The current-strength being still further increased to a certain point, muscular contraction will follow closure of the circuit with the anode in contact with the nerve, both of the previous contractions also occurring more vigorously than before and the more markedly in their order of occurrence; finally, a contraction will occur if the circuit be opened with the cathode in nervous contact, but the current required to produce it is unbearable. The peripheral portions of nerves are less irritable than their centres. The above reactions assume the nerve laid bare and the electrode applied immediately thereto. This gives, for a *normal galvanic nerve* reaction, formula—

$$\text{Ca. Cl. C.} > \text{An. O. C.} > \text{An. Cl. C.} > \text{Ca. O. C.}$$

When the electrode of a galvanic battery is applied to muscular tissue, contractions also occur; but the normal sequence or formula differs somewhat from the normal nerve reaction, and will be found as follows:—

With the weakest current, contractions will occur with the cathode in position upon closure of the circuit (Ca. Cl. C.); upon increasing the current, the next contractions will ensue upon closing the circuit with the anode in position (An. Cl. C.): this will be followed by contractions upon opening the circuit with the same pole in place (An. O. C.); but, like the final contraction (Ca. O. C.), this requires a very strong current—too strong for endurance. This gives, for a normal muscle reaction, formula—

$$\text{Ca. Cl. C.} > \text{An. Cl. C.} > \text{An. O. C.} > \text{Ca. O. C.}$$

With a very strong current, the ensuing contractions, instead of being short, sharp, and quick in character, as they always are in health to moderate stimulation, become long in duration, slow, and tetanoid. After the electrodes have been applied for *a considerable* length of time, the current flowing, it has been

observed that the nerve irritability has decidedly increased, and that contractions more readily take place. Experiments upon the healthy human being are naturally surrounded by many and often insurmountable obstacles ; therefore, it can be readily understood how much more certain and accurate are the observations of the physiologist. To observe the normal muscle reactions of a subject, the anode should at first be placed upon an indifferent point, as the sternum or spine, and the cathode upon the epidermis where the entrance into the muscle of the motor nerve is most superficial ; the current is now gradually turned on by means of the controller and interruptions occasionally made with the button upon the interrupting electrode handle : when the requisite current-strength has been obtained, contractions will occur at each closure of the circuit (Ca. Cl. C.). Now let the current be reversed by means of the commutator—the former cathode thereby becoming the anode—and interruptions will produce no contractions ; but, upon increasing the current to a certain point, contractions will follow each closure of the circuit (An. Cl. C.), the first contraction (cathodic) also occurring, and stronger than when first observed. With a still further increase of current, contractions will appear when the circuit is opened with the anode in place (An. O. C.) ; and with a very strong current—indeed unendurable—cathodic opening contraction (Ca. O. C.) may be noted. To obtain the anodic opening contraction the current should be permitted to flow uninterruptedly through the tissues for a brief period of time and then the interruption made, the continued action of the current having been observed to facilitate the occurrence of this contraction.[1]

In all examinations it should be an invariable rule to make use of the milliampere meter and carefully register for future reference the amount of current required to produce the various contractions. In this way as much scientific accuracy may be attained as our present knowledge permits ; without it all results must be inaccurate and unreliable. It is superfluous to state that in order to transmit a current through the human body both poles must be brought in contact therewith. The pole in proximity to the nerve which supplies the muscles under examination is called the *active pole ;* the other, placed at a distance

[1] See last paragraph of Preface.

—*i. e.*, the sternum or spine—called the indifferent pole: this constitutes the polar method of examination. A long-existing controversy as to whether muscle tissue in itself is susceptible to the influence of electricity, or whether it contracts solely in response to irritation of the nerve-filaments supplying it, seems to be satisfactorily settled, independent muscular irritability having been thoroughly demonstrated. This is a fact of considerable diagnostic and prognostic importance. It has been observed that the faradic current has less influence upon muscular tissue than upon the motor nerve supplying it, due perhaps to the short duration of each faradic current. The galvanic contraction of muscular tissue takes place chiefly upon closure of the circuit; in exceptional cases opening contractions occur, but generally only from an increase of current, and after a continued interval of closure during which the current is flowing and rendering the tissues more irritable. The muscles retain a certain amount of contraction for an interval of time following both closure and opening of the circuit if the current be sufficiently strong; this is called closure and opening duration contraction, indicated by D. To the rapidly interrupted faradic current the muscles react with a steady tetanic contraction, depending for strength upon the amount of current and the proximity of the active electrode to the motor nerve, *i. e.*, the entrance-point of the nerve into the muscle.

Normal muscular tissue should react with a prompt, quick, lightning-like contraction to the moderate stimulation of the galvanic current upon closure of the circuit.

Electrotonus.

When a galvanic current is passed through a motor nerve it exerts an influence throughout its entire extent, but most decidedly in the region of contact of the electrodes: in the neighborhood of the anode this influence is decreased; at the cathode the reverse takes place and the irritability is increased: the former is called *anelectrotonus*, the latter *catelectrotonus*.

Satisfactory results have by no means been attained by investigation of this subject as applied to living human beings; never-

theless, it may be assumed that the phenomenon of electrotonus has been, in the human being, definitely established. This phenomenon is most intense throughout a straight line from pole to pole.

Effect of the Galvanic Current upon Sensory Nerves.

The application to a healthy subject of a certain strength of the galvanic current produces a peculiar, characteristic sensation, as of innumerable pin-pricks, which is soon followed by a steady, burning pain; this is thought to be largely due to the electrolytic action of the current. This effect of the current is apparent both at the point of application and throughout the distribution of the nerve. The sensory impression, in its strength and action, follows a rule very analogous to the motor effect—*i. e.*, it is felt most decidedly at the moment of closing and opening the circuit, the cathodic closure being the strongest.

Faradism produces at each opening and closing of the circuit a burning, pricking sensation, which is also distributed to the peripheral extremity of the nerve within touch of the electrode; if a dry electrode be applied, as the faradic brush, very severe and painful sensations of burning will result. Experimentation upon isolated sensory nerves has been unsatisfactory in exactness of detail; but it seems to be agreed that every distinct muscular contraction carries with it at the same time a peculiar sensory impression altogether separate from that of the integument.

Experiments upon the Nerves of Special Sense in the healthy human subject have proved quite satisfactory, the faradic current possessing little or no influence; the galvanic very considerable. Application of the electrode to the eye causes a sensation of flashing light upon making and breaking the current, the color of the light varying in a manner somewhat analogous to the rule of muscular contractions—*i. e.*, Ca. Cl. being the strongest; moreover, the pupil may be made to contract and dilate in response to the current.

By stimulating the auditory nerve characteristic results may be obtained of sound, varying in intensity. The sense of taste can likewise be elicited by galvanism, and is present continuously during the flow of the current and not only upon making and breaking the circuit. The sense of smell has only been slightly brought into play by means of electricity. The secretions and vaso-motor nerves are both affected by electricity. The sympathetic system, obscure in itself, is also responsive to the action of electricity. It is believed that faradization of the cervical sympathetic results in dilatation preceded by contraction of the vessels upon the same side of the face, together with other physiological actions, such as increased rapidity of the heart's action, dilatation of the pupil, etc.; while galvanism produces much less marked phenomena. Application of electricity to the skin causes redness—hyperæmia produced by dilatation of the capillaries; this effect is much more marked following the use of the faradic brush than from moistened electrodes. The galvanic current creates distinct redness and even a papillary eruption of the skin, followed by desquamation; while stronger currents produce still more decided results. Faradization of the brain is ineffective, but galvanization is followed by positive results. Vertigo is very generally observed as one of the earliest effects of galvanism of the brain, and with sufficient current may extend even to staggering and falling, the effect being greater with a transverse current than an antero-posterior one; but this is much more important as a subjective than as an objective symptom. Vertigo is often continuous with the flow of the current. Nystagmus may also occur, accompanied by a certain amount of confusion of thought. The spinal cord should be reached by means of large electrodes. Experimentation upon the lungs has not resulted satisfactorily. Galvanism may produce contraction of the gall-bladder if applied externally over that region. Many of the functional actions of the muscles of the pharynx, larynx, and œsophagus may be brought about by electricity, as also those of the stomach and intestines. Contraction of the bladder promptly results from properly applied stimulation of the neck and walls of that organ.

The cataphoric effect of electricity may prove of considerable

service, and has been utilized to promote the passage of salts through parts of the human body.

The action of electricity in disease is obscure and not yet susceptible of elucidation; it is, however, probable that changes of different nature take place in the tissues of the body, thereby altering its nutrition.

Electrical Examination of Nerves and Muscles.

To examine nerves and the muscles they supply the current should be applied as directly and in as circumscribed a space as possible; the milliampere meter should invariably be used and the current carefully measured, the object being to bring the current into localized action upon the nerve-trunk with as little dispersion into surrounding tissue as practicable. To accomplish this, a small electrode should be selected for the active one, greater density being thus secured, but this is of course not without limit, for, if the electrode is very small, the resistance becomes too great to permit a proper flow of current. A convenient size for diagnostic examinations will be found between the diameters of one-half and one inch. The indifferent electrode, upon the other hand, should be quite large, the only limit being convenience of application; by this means the current is practically only effective at the point of application of the active or denser electrode. The large electrode should be placed upon an indifferent point, *i. e.*, the spine or sternum, the latter being commonly preferable because of the comparative absence of nerves and muscles which might otherwise more or less interfere with the examination, and also because the patient may, with facility, assist the operator by holding the electrode in position.

The normal parts should, invariably, be examined first, and comparison made with the diseased parts. The examination should always be conducted in precisely the same manner, and it is often desirable to use the same battery and appliances if results are for comparison.

Quantitative Examination of Nerves and Muscles.

The method in use with the faradic current is simply to note the amount of primary coil necessary to cover with the secondary in order to produce the slightest contraction of the muscles under observation, or, in another form of battery, the length of cylinder withdrawn in order to cause the same result with the proper electrodes in position. Symmetrical portions of the body should be compared, the current being the same. If the disease be unilateral, but when parts located in different portions of the body must be compared, great uncertainty enters into the result; the uncertainty is considerably enhanced where comparison is made with another and a healthy body, as the resistance of individuals varies greatly. In order to still further eliminate the elements of uncertainty from electrical examinations, Erb entered into an extensive line of investigations, from which he has established the fact that a constant relation exists between resistance offered by the four principal portions of the body, and he avers that any very appreciable variation from his standard may be looked upon as pathological; consequently, changes may be noted in a patient from an individual examination without further comparison. To illustrate this, the same learned writer selects certain nerves, and with a medium-sized electrode notes the amount of cylinder withdrawn, or the amount of coil covered, necessary to cause the minimum muscular contraction with a faradic current. The faradic current should always be used first because it promotes no change in resistance.

With the same electrode now attached to the galvanic battery and well moistened, the deflection of the milliampere meter needle is next noted; a definite strength of current being used and not interrupted, *i. e.*, "stabile." Application is of course made to the same localities previously examined with the faradic battery, the cathode being used as the active pole. The points selected should be corresponding nerves on both sides of the body. The current noted should be the weakest capable of producing muscular contractions. One set of notes shows the relative faradic irritability of the different pairs of nerves; the

other the relative resistance to the flow of the galvanic current. The same observer claims that these bear a constant relation in healthy individuals under similar circumstances of age, society, sex, and physique. The nerves selected by Erb for comparison were the frontal, spinal accessory, ulnar, and peroneal. In a table prepared from a number of these experiments he shows that the results are practically the same for both sides of the body, and that the four pairs of nerves are almost equally irritable to the same minimum current. A record of the current strength, as indicated by the meter or rheostat, is only reliable in reference to both sides of the same subject. For comparison with different subjects, it is entirely unreliable, owing to the difference of resistance to conduction in different persons.

In order to obtain accurate results, the current should be of the same density; that is, the electrodes should be of the same size, and the current of the same strength. The pressure and manner of application generally should be as nearly similar as attainable. If all these qualifications are fulfilled, and the current necessary to induce minimum contractions deflects the needle to a greater extent, irritability may be considered as impaired; if to a less extent, irritability is increased. Anomalous distribution of nerves contributes one important source of error to this form of examination.

Voltaic Alternative.—The effect of the galvanic current will be found to be greater with either pole if the opposite pole has been permitted to remain in position for some time immediately preceding; and the longer it has been in position the greater will be the observed effect if the poles be reversed. Also, the effect will be found much greater if the poles be reversed quickly than if reversed slowly. Reversal of the poles is termed "the voltaic alternative."

By Qualitative Electrical Reactions

of muscles is meant whether or not the contractions occur in normal sequence, possess the same characteristic manner of contraction, the same duration, and the proper strength. To determine this, the method above described is employed, and

Erb very justly insists that, in order to work intelligently, the practitioner should be familiar with the peculiarities presented by the contractions governed by the more important nerves, at least. This, of course, can only be obtained by experience. The manner of contraction is sometimes referred to as "modal."

Muscle and Nerve Degeneration.

Qualitative changes occur in both nerve and muscle, though they react differently to the galvanic and faradic currents. An increase of irritability to both currents is evinced by a more easily induced contraction of the muscles. Diminished irritability of both nerve and muscle is characterized by the necessity of employing stronger currents, both faradic and galvanic, to produce the requisite contractions.

Increase of electrical irritability is looked upon as a condition involving no particular importance. **Decrease of electrical irritability,** on the other hand, is highly serious and involves grave issues. It may be slight, or it may extend to entire "extinction of faradic excitability." Bare muscular tissue will preserve its excitability for a considerable period of time after all effect of stimulation through the epidermis has disappeared. This can be frequently demonstrated by puncturing the skin with the active electrode, and by thus bringing it in direct contact with muscle tissue. In certain diseases the muscular contractures to galvanic stimulation disappear in regular order: Ca. O. C. vanishing first, followed by An. O. C., and that by An. Cl. C. and Ca. Cl. C., respectively. The contractions, which in health are always quick, sharp, and lightning-like, assume a slow tetanoid character, which is extremely significant.

In other diseases the sequence of the contractions is changed, An. Cl. C. occurring before Ca. Cl. C., and also slow and tetanoid in character. This is a point of vital importance in electro-diagnosis, constituting, as it does, the essence of "*the reaction of degeneration.*"

In the peripheral portion of *nerves* a decrease of electrical irritability is generally present only when degeneration is in progress. It constitutes a symptom which, if carefully ascer-

tained and clearly established, may be safely relied upon as a forerunner of complete faradic and galvanic extinction. The muscles, however, act differently. Entire loss of faradic irritability may be present; but the galvanic current induces an irritation which undergoes an entire series of changes, both qualitative and quantitative. Frequently, total extinction of reaction is the final condition. In some muscular conditions irritability is merely diminished, and no graver electrical symptoms supervene. These facts occasionally assume proportions of extreme prominence and importance. Erb reports a case in which he was enabled to establish the honesty of an invalid who was suspected of malingering, and to protect him from grave injustice, the nature of the case being so obscure that quantitative electrical symptoms alone could be relied upon, all others being in doubt.

The diagnosis of the central spinal lesions may be particularly aided by means of electricity.

Reaction of Degeneration.—This term, now in such universal use, was first utilized by Erb, and was intended to mean the series of changes occurring in electrical irritability, both qualitative and quantitative, owing to degeneration or disease of healthy nerve and muscle. The effect of the faradic current diminishes and disappears. The effect of the galvanic current undergoes various decided changes, but preserves its power of irritating muscular tissue. In some stages this occurs even to an increased degree. The qualitative changes of the galvanic current in disease of the nerve are invariable and most important.

A lesion of a motor nerve, either at the spinal centre or in the course of its peripheral distribution, of sufficient importance to cause paralysis, will commonly be promptly followed by marked electrical changes, both faradic and galvanic. The nerve will evince a progressive decrease of electrical excitability, while at the end of a week it will have ceased entirely. In rare cases the period of decline may extend over two weeks. The point of departure is always at the extremity nearest the injury or lesion, degeneration proceeding thence toward the periphery. When the lesion results in incurable disease the nerves remain

forever inert. In trifling cases recovery takes place early. In many recovery only ensues after a more or less prolonged interval.

When reparative action has commenced, and the nerve advanced sufficiently toward health, electrical excitability returns, both faradic and galvanic, recovery being first noticed at the point of beginning degeneration, and slowly extending toward the periphery. Recuperation proceeds slowly and gradually, months frequently elapsing in the process. Both the galvanic and faradic currents recover effectiveness *pari passu*.

Frequently, muscles may respond to voluntary effort, while electricity continues without effect, tending to show that, while the nerve is in condition to transmit one kind of impression (voluntary), it by no means follows that all are transmittable.

In degeneration muscles do not show electrical reactions similar to nerves. This, however, is not true in relation to the faradic current, for here the reactions are identical both in quantity and quality. It is in the use of the galvanic current that the chief difference between nerve and muscle reaction of degeneration is apparent. To the faradic current both muscle and nerve become gradually less sensible as degeneration progresses, ending in complete insensibility, as stated above. The faradic current has no effect on muscle tissue except through the nerve supplying it. Thus if the nerve be paralyzed by curare, the muscle remains inert to this current. To the galvanic current, however, muscular tissue for the first few days contracts, with a somewhat diminished activity. It does not respond so readily to a certain strength of current as it would were the condition normal. After this, and for several days succeeding, the irritability of the muscle increases, sometimes to a great extent. This may last for several weeeks—three or four; and some time *during* this condition a change in the normal sequence of contractions occurs; the contractions change also in character as well as in quality. They assume a slow tetanoid form in place of the sharp, quick, lightning-like, normal reaction. The tetanic condition continues during the flow of the current, the strength of current required being notably small. This slow tetanoid contracture, accompanying a *weak*

current, is considered by Erb thoroughly characteristic of degeneration. The alteration in the sequence of contractions is also remarkable and of equal importance. Soon in the stage of degeneration the An. Cl. C. becomes equal to the Ca. Cl. C.; a little later it exceeds it. This is accompanied by changes in the condition of the succeeding-contractions Ca. O. C., gaining upon An. O. C., but *never equaling* it; so that we have, for the normal muscular reaction to galvanism, *the formula*—

Ca. Cl. C. > An. Cl. C. > An. O. C. > Ca. O.C.

For the reaction of degeneration formula we have—

An. Cl. C. = Ca. Cl. C. or An. Cl. C. > Ca. Cl. C. > An. O. C.

diminished, but always > Ca. O. C.

This state remains for several weeks, after the lapse of which a change takes place in the irritability of the muscles, but not in the quality of the contractions. The sequence remains the same; but the contractions gradually require stronger currents, until at last, in grave cases, the An. Cl. C. takes the place of Ca. Cl. C. entirely, the latter having totally disappeared. The contraction remaining at this stage is extremely weak. It may require months to reach this point of degeneration; in fact, several years of gradually decreasing electrical irritability is by no means rare. In cases less grave in character, and where a cure results, the course is one of an entirely opposite nature; the muscles, with various degrees of promptitude, regain the normal character and quality of irritability. The difference observed between the action of the galvanic and faradic currents may all be due to the instantaneous duration of the latter. The galvanic current itself, if subjected to equally rapid interruptions, seems to lose much of its distinguishing characteristics.

Electrical currents seem, beyond reasonable doubt, to bear a peculiar and reliable relation to the functions of muscle and nerve-tissue both in health and disease. While they remain healthy, normal electrical reactions are certain. When degeneration begins, coincident change in the reactions may be confidently looked for.

If a lesion occurs in the continuity of a nerve, whereby the periphery is cut off from the central communication, Wallerian degeneration soon takes place. The nerve undergoes degeneration from the lesion towards its peripheral distribution (motor nerve), the sheath of the nerve suffering first a granular breaking-down and a nuclear proliferation, which is followed by a denuding and consequent degeneration of the axis cylinder. The process runs a rapid course, only a few days being required (three or four). The effect of this upon the muscles supplied is, of course, disastrous, their elements undergoing fatty and granular degeneration with increase of connective tissue.

If the lesion be traumatic and capable of reparative action, the nerve in due time recovers its normal condition, the restoration being followed by a like change in the muscles. In case of permanent nervous destruction, the muscular tissues gradually waste away until finally nothing remains save a mass of connective tissue. Even in favorable cases recuperation of the muscles is a slow and tedious process.

Destruction of the nerve and reaction of degeneration occur simultaneously, the latter depending upon the former. During the first week no degeneration has been found in the muscle fibres themselves, but it is rarely delayed beyond that period. Some confusion may arise in cases where reactions of degeneration have existed in both nerve and muscles. Subsequent examination shows the nerve to respond normally, while the muscles still evince degeneration. This admits, nevertheless, readily of explanation—*i. e.*, the nerve has undergone reparative process, and has regained its normal standard of health, but the muscles have not as yet been regenerated. Pathological changes and reactions of degeneration begin together and advance at the same rate.

Partial reactions of degeneration occur. They are characterized by more or less diminution of irritability to galvanic and faradic currents. It has been noted, more especially in connection with the maximum contraction, that a very strong current produces a decidedly weakened response, the muscles preserving unchanged the normal sequence. These cases may generally be given a comparatively favorable prognosis.

Between normal reaction and total disappearance of electrical excitability all grades and conditions will be found. Even the same muscle may, in certain conditions, show different electrical reactions in different parts (progressive muscular atrophy).

De R (reaction of degeneration) will be found typically in cases where the peripheral terminations of motor nerve-fibres have for any reason ceased to connect with the centre in the anterior cornu of the spinal cord, whether this be caused by destruction of the centre itself, or by the existence of a lesion in the continuity of the nerve, such as pressure, injury, inflammation, etc.

Conclusions as to the existence of reaction of degeneration will often be difficult to arrive at, and many apparent contradictory results will confuse and discourage the tyro. As in other branches of the medical sciences, typical cases are more rarely met with than perhaps generally supposed. Experience, careful work, and, above all, acute accurate observation, will, in the end, achieve for the conscientious worker results which will, in the field of diagnosis, notably reward him. Often the changes are so slight that the experienced observer alone is capable of estimating their significance.

When degeneration has advanced a considerable extent, it is often necessary to employ a current of great strength in order to obtain any contractions at all. This is accomplished, of course, by recourse to the means already stated, *i. e.*, by rendering the skin as conductive as possible, employing large indifferent electrodes, and, in order to isolate muscles, bringing the two electrodes close together that both may be within the muscles area. Erb remarks a manner of distinguishing contractions of adjacent healthy muscles due to diffusion of the current, which the writers have frequently verified. It will be found that sound neighboring muscles will respond to the closure of the circuit by a sharp, quick contraction, and immediately thereafter a slow, feeble characteristic degenerate contraction will occur in the muscles undergoing pathological changes. During the last stage of degeneration slight contractions may be obtained after repeated failure in previous examinations ; hence, no patient should be dismissed without several separate examinations, if the circumstances of

the case admit of doubt. The slow, feeble contraction of certain diseased muscles, following the quick normal contractions of contiguous muscles from circuit closure, is well and typically illustrated in some cases of lead wrist-drop. Erb speaks of this, and the writers have under treatment now, in the neurological department of Jefferson Medical College Hospital, a man who has been for many months suffering from this disease. Rather strong galvanic stimulation of the extensor muscles of the forearm produces well-defined normal contractions of the flexors, followed by an extremely feeble slow reaction of the extensors. In the first stage of degeneration, it may often be observed that Ca. Cl. C. is very strong and quick, but an ensuing An. Cl. C. is tetanoid, tardy, and characteristic of degeneration.

Sensory.

It is scarcely surprising that our knowledge of the action of electrical currents upon the sensory nervous system is imperfect, the physiology and pathology relating thereto being still so exceedingly obscure and unsatisfactory. Electricity, although of incalculable value in the scientific management of diseases involving the motor system, must as yet be considered unavailable in our efforts to throw light upon the irritability, location, conductivity, and other functions of the sensory nervous system. That all this may eventually be realized should not be doubted.

The cutaneous filaments of the sensory nerve-fibres convey the impressions created by the electrical currents, and we recognize an increase and impairment of this function, corresponding to a certain extent with the definite reactions of the motor system.

This constitutes electrical *anæsthesia* and *hyperæsthesia* of the epidermis. In some cases these symptoms are important. The diagnosis of diseases involving the sensory tracts of the cord is materially aided thereby. It has been remarked that in posterior sclerosis of the spinal cord, if tactile sensation remains normal and analgesia exists, then the minimum sensation to pain requires a great increase of the faradic current. Much contradictory evidence, however, is adduced.

Special Sense.

Auditory.—The results of research in this direction have been interesting, and somewhat satisfactory and definite both as to diagnosis and treatment.

Insensibility of the auditory nerve means a sluggish reaction to galvanism ; ordinary Ca. Cl. producing no effect, and an extraordinary strength of current merely meeting with feeble, if any, response. Diagnosis of this condition is somewhat difficult and uncertain, inasmuch as even in health it is not always possible to obtain reactions of this nerve.

Increased sensibility of the auditory nerve means that it responds to the stimulation of galvanism with greater promptness and celerity than in health. The qualitative or normal sequence is preserved, an infinitesimal current being frequently sufficient to produce the entire range of auditory reactions. Ca. Cl. reaction is followed by An. Cl. reaction with currents of almost equal strength, and so exceedingly weak that the milliampere meter can, with difficulty, be detected as registering any current at all. The sensation of sound is much exaggerated, and continues longer than in health.

Auditory sensibility in a heightened condition is far from uncommon, and frequently exists with little or no disorder of the hearing function. On the other hand, it accompanies many of the minor as well as some of the most serious lesions of the ear and adjacent structures. It also exists in connection with various central diseases, as cerebro-spinal meningitis, locomotor ataxia, etc. It has been claimed that many cases of tinnitus aurium originate in the nerve itself, and that such may be promptly relieved by application of the galvanic current An. Cl. and An. D. Ca. Cl. and Ca. D. have been found to aggravate the complaint. Tinnitus, due to lesions external to the nerve, is unaffected by electricity in any form. This fact is not without importance in a diagnostic point of view. The auditory reactions now being discussed, it is needless to repeat, are entirely those of the special sense of sound, and are obtained by placing one "*medium*" electrode properly moistened upon the tragus, pressing it gently inward, but not sufficiently to obstruct the external

auditory meatus; the other, or indifferent, electrode may be placed upon the sternum or spine. It should be *larger*, and also well moistened. The current then should be gradually increased, and the sensations of the patient following occasional closure and opening of the circuit carefully noted, both qualitatively and quantitatively. The latter refers to the intensity of the sound, the former to its character. As in all other electrical applications irritability will increase with the duration of the treatment. Exhaustive experimentation has been made in connection with this subject, and the peculiarities of the sounds caused by electrical stimulations carefully analyzed. It has been well established that both qualitatively and quantitatively the reactions preserve a certain constant relation in health and disease. A more extended discussion of these reactions, however, would exceed the scope of this work.[1]

Optic Nerve.

Researches in this direction have thus far proved without adequate reward, and but little definite information has been recorded. A few facts, however, should be noted. The active electrode of a galvanic battery when applied to the vicinity of the orbit, and the circuit made and broken—the indifferent electrode being in position upon the sternum or spine (nape of the neck)—produces in the healthy subject remarkable sensations characterized by luminous spectra varying with the current employed.

In diseases of the optic nerve changes have been shown to exist in the electrical reactions; but either sufficient data have not been secured, or the results of experimentation have proved contradictory. Thus, no classification of the optic nerve reactions of degeneration has as yet been well established.

In some diseases of this nerve its irritability to galvanic stimulations is impaired, and not infrequently entirely destroyed. In optic neuritis, followed by atrophy, the sensation of light, as caused by interruption of a galvanic application, is lost to a

[1] See Erb and De Watteville on Electricity.

greater or less degree, depending upon the amount of involvement of the nerve. Amaurosis in its last stage, from whatever cause, traumatic or tumor, entails entire loss of galvanic reaction.

Taste.

The sense of taste may be stimulated by placing an electrode upon each cheek of the patient, and interrupting the current as it flows transversely through the mouth. In disease of the nerve governing taste, its electrical irritability undergoes changes, but no definite results have thus far been formulated. It may be still better, in order to observe this reaction, to place the active pole upon the tongue and the other on the mastoid process.

Vaso-Motor.

But little advance in the knowledge of the effects of electricity upon the vaso-motor system can be noted since Hitzig recorded his observations in cases of palsy of the axillary nerve. He stated that in the resulting area of anæsthesia the skin assumed a pallid hue when subjected to the influence of the galvanic current. The effect of electricity in health is to promote congestion of the capillaries. A strong *labile* current is the one employed.

Stabile application of electricity is accomplished by placing the electrodes in the desired position and gradually turning on the current. The electrode should not be moved from its place, nor should the circuit be interrupted. After sufficient time has elapsed, the current of desired strength, having flowed continuously, is gradually turned off and the electrodes removed when it has entirely ceased to flow, and not before.

Labile Application signifies a galvanic current slowly interrupted. It is often applied by placing one electrode at the indifferent point and by slowly passing the other or active one over the parts requiring treatment—*stroking the part.*

The Direction of the Current is probably unimportant, and simply refers to the location of the cathode; the current, of course, proceeding in a direction *to* the cathode *from* the anode.

An Ascending Current flows *from* the periphery *toward* the nerve-centre.

A Descending Current flows in the direction from the *centre* toward the *periphery.*

As a Curative Agent.

The value of electricity as a curative agent is a subject to be approached with caution, and, above all, discrimination. That electricity ranks high as an aid in the establishment of correct diagnosis is indisputable; that it is capable of achieving much good as a therapeutic agent, few fair-minded physicians will be inclined to gainsay. Its range of usefulness is practically unlimited, and to its intrinsic qualities may be superadded the psychical influence it so frequently and pre-eminently possesses. The marvellous, almost miraculous, cures recorded by so highly-respected and honored authorities as Ziemssen and Erb must be, and are, fully credited by a preponderating proportion of all physicians of every nationality.

The recent utterances of reliable authorities go far to establish the opinion that in the treatment of paralysis the ultimate benefit of electricity depends entirely upon its power of causing contraction of the muscles involved. Our comprehension of the *modus operandi* of electricity as a therapeutic agent is exceedingly limited, and must naturally remain so until our knowledge of pathology and kindred sciences shall have advanced far beyond its present limits, and until brighter light has been shed upon the obscure causes of functional diseases of the nervous system in their various manifestations. So close, indeed, does the analogy seem in many ways between nervous functionation and electricity, that the hope may, without optimism, be cherished that the elucidation of the former will lead to a thorough, comprehensive, and useful application of the latter, and *vice versa.*

Gynæcologists are to be congratulated most cordially as having occupied the van in obtaining therapeutic results from electricity—results which, at first almost discredited by the profession at large, all fair-minded observers must now admit. If

this really invaluable agent has been retarded in its mission to relieve pain and to restore the priceless boon of health to many miserable women—miserable, alas, only because of its want—the censure should not be placed upon the so-called skeptics only. To the enthusiast, who, for want of proper brain balance, has persistently exaggerated results (who will doubt it ?), and to the charlatan possessed of enough but for his own selfish purposes, should be accorded their full quota of blame, if blame there be.

In this city Dr. G. Betton Massey, to whom the profession is indebted for a most valuable treatise upon this subject, appears to the writer to have earned appreciation and confidence by his earnest and conservative work in this extensive field.

From what has already been stated regarding the relative effects of faradism and galvanism in health and in disease, it follows that the former is of much less value as a therapeutic agent than is the latter. Faradism possesses practically no catalytic or cataphoric power, and, as far as is known, produces but little change of nutrition in the tissues. Its value is chiefly apparent as a counter-irritant, and in the treatment of anæsthesia by means of the dry electric brush, etc. As an exciter of muscular contractions it has undoubted value, but is far inferior to galvanism, for the important reason that it induces contractions only in those fibres of the muscle which are in healthy accord with the motor nerve governing them ; whereas galvanism will invoke muscular contractions even in cases where the motor nerve is entirely cut off from its functionating centre, and will continue so to do until the muscle-fibres themselves degenerate into fibrous tissue, etc., and thereby lose their distinctive qualities. Consequently, in paralysis depending upon a lesion of the nerve, the rule should be to employ galvanism, even where faradic excitability apparently has not been entirely lost, or, having disappeared, has returned, because thereby we may feel assured that *all* the muscular fibres will respond to the stimulation, as well those nutrified by nerve-filaments in a state of healthy action as by those which have, and still remain, degenerated. Moreover, the influence exercised by this current over the nutrition and circulation of the paralyzed part cannot fail to be

reverse order must be observed. In such applications to the face, with one electrode at the nucha, the same writer suggests that the active electrode be first placed upon the hairy scalp and very gradually drawn down over the face, thereby producing a gradually increasing effect. In treating very nervous subjects, as well as children, who often have a dread of electricity, it is often well first to apply the electrode with no current flowing, and thus allow the fear to subside.

Unnecessary pain must always be avoided, and to this end, as well as for other important reasons, the electrodes should be frequently well moistened with warm water.

Labile application, we have already said, consists of keeping one electrode upon an indifferent point, while the other is slowly stroked about the skin of the diseased part with a moderate and constant amount of pressure. No decided muscular contractions are induced, because the current is not at any time entirely broken, but a very stimulating effect on nutrition is obtained. This method combines the chemical effect of the stabile current on deep parts with the stimulating effect of an interrupted current on muscular contractility. The cutaneous circulation is also improved by stimulation.

The interrupted galvanic current, which has for its object muscular contraction, may be used in two modes. In one the indifferent electrode is held stationary in position, and the active (generally the cathode) applied and withdrawn alternately ; each time it is applied the circuit is made, and each time withdrawn the circuit is broken. In this way contractions occur. But a much better way is by means of the interrupting electrode handle, whereby the circuit may be closed and opened with great facility. Strong contractions may also be caused by inducing voltaic alternative by means of the commutator, the electrodes being held in position. This is the most powerful, and often has been found to induce strong contractions in muscles the seat of atrophic paralysis, where response had almost entirely ceased to ordinary interruptions.

Faradization.—If we desire a local effect upon the skin, it should be well dried, and application made by means of the dry brush. The indifferent pole should be an ordinary large elec-

trode, well moistened. The brush should be slowly stroked over the part.

For faradization of muscles, etc., the handles of the electrodes should be held by the operator, or both electrodes may be held in one hand, leaving the other free to regulate the current. This is very necessary, as certain portions of the body are much more sensitive than others ; thus, all bony prominences are peculiarly sensitive.

Central Galvanization.—One pole, preferably the cathode, should be placed at the sacrum ; the anode is then applied to the forehead for a length of time varying according to circumstances—but five minutes will generally be found quite long enough. The pole should then be drawn to the vertex, and from there along the pneumogastric and sympathetic route in the neck, thence down the entire length of the spine. The current must be carefully regulated, much more care being required about the head than along the spine.

General Faradization may be accomplished by placing one electrode at an indifferent point—any part of the trunk, or, using a large copper plate, at the soles of the feet, and drawing the other about the body generally. The application may last ten to fifteen minutes.

Subaural Galvanization.—This method is said by DeWatteville to be purely empirical ; and yet the results obtained in diseases of the brain and spinal cord are admitted by him to be very gratifying. It is used by placing the cathode, a medium electrode, under the ear, and a large negative electrode over the lower cervical and upper dorsal vertebræ.

Galvano-Faradization.—This method was introduced by DeWatteville ; he unites the secondary coil and galvanic battery in one circuit by connecting, by means of wire, the negative pole of one to the positive of the other.

A slowly interrupted faradic current is obtained by means of a mechanical device, described in a previous portion of this work. It is useful for the purpose of stimulating muscular contractions, and in its effects must be akin to galvanism.

By the kind permission of Dr. Rockwell, and of his publishers, Messrs. Wm. Wood & Co., of New York, the writers have the

valuable privilege of inserting the following plates (Figs. 45 to 56), illustrative of Galvanization and Faradization, as well as of the method of Isolated Muscular Stimulation (Fig. 50).

The writers have also particularly to thank the same gentlemen for additional courtesy in supplying them with the new and improved plates, which are about to appear in the forthcoming fresh edition of an exhaustive work upon this subject by Beard and Rockwell.

FIG. 45.

GENERAL FARADIZATION.—Application to the stomach. (Beard and Rockwell.)

FIG. 46.

GENERAL FARADIZATION.—Application to the spine. The hand of the operator is on the metallic tube, in a position to increase or diminish the current, as may be needed. (Beard and Rockwell.)

FIG. 47.

GENERAL FARADIZATION.—Application to lower extremities. (Beard and Rockwell.)

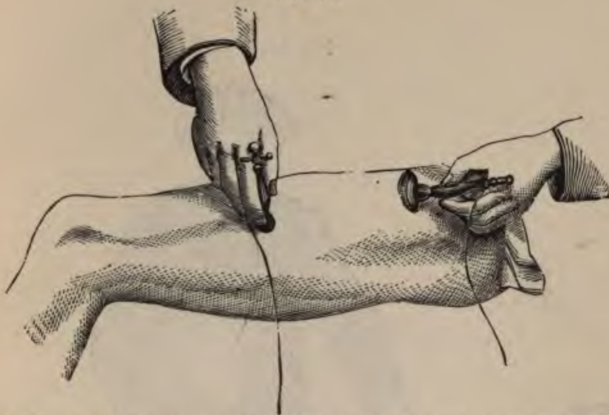
FIG. 48.

GENERAL FARADIZATION.—Application to the head by the hand of the operator. The patient may be protected from cold by a shawl or other convenient covering. (Beard and Rockwell.)

Fig. 49.

Faradization of Popliteal Nerve and Peroneal Muscles.—Foot brought upward and outward. (Beard and Rockwell.)

FIG. 50.



FARADIZATION OF MUSCLES OF THIGH, CONTRACTION OF QUADRICEPS.—(Beard and Rockwell.)

FIG. 51.

FARADIZATION OF FACIAL NERVE AND MUSCLES.—Eyelid firmly closed and mouth drawn to one side. (Beard and Rockwell.)

FIG. 52.

GENERAL GALVANO-FARADIZATION.—Application to the spine by a sponge-holder. A double electrode is used, one part of which is connected with the faradic, the other with the galvanic. The copper plate is also connected with both, and applied to the feet. (Beard and Rockwell.)

FIG. 53.

CENTRAL GALVANIZATION.—One pole over epigastrium or abdomen, and passed beneath the loosened clothing up and down the spine from seventh cervical vertebra to coccyx. (Beard and Rockwell.)

FIG. 54.

CENTRAL GALVANIZATION.—One pole to epigastrium, the other along inner border of sterno-cleido-mastoid muscle, labile. (Beard and Rockwell.)

FIG. 55.

CENTRAL GALVANIZATION.—One pole at epigastrium, the other at back of neck. The first to seventh cervical vertebræ. (Beard and Rockwell.)

FIG. 56.

GENERAL GALVANIZATION.—One pole at the epigastrium, the other on cranial centre, the hair being moistened. Previously, the electrode may be applied, labile, to the forehead. (Beard and Rockwell.)

Electro-Diagnosis.

One source of error in electro-diagnosis consists in the variation of resistance to the electrical current offered by the skin. We may find that a muscle on one side of the body requires a considerable increase of current to induce contraction, and therefore may assume degeneration when in reality perfect health exists; careful employment of the milliampere meter will alone guard against this.

Change in excitability of nerves, due to previous and prolonged application of currents, is an important source of error, and may be guarded against by refraining from testing a nerve until sufficient time has elapsed during which all previous electrical excitement may subside.

The diffusion of currents to neighboring muscles and nerves is another annoying complication and source of error in diagnosis, and cannot always be guarded against. In all cases, the muscles under examination should be relaxed as much as possible, and the others restrained, if practicable, by mechanical means.

A muscle may be partly healthy and in part degenerated; here the maximal contractions are diminished; the serial, or qualitative contractions, may appear normal, yet following the An. Cl. appear slow, tardy contractions, typical of degeneration.

To make a proper electro-diagnosis, the patient should be in a position insuring good light, relaxation of muscles, and facility of examining symmetrical parts of the body. The patient should be told to abandon all volition over the muscles involved. The indifferent electrode should then be fixed in position, the sternum being generally preferred; the other electrode should be small, with an interrupting handle held in the hand of the operator. Water should be used freely both upon the skin of the patient and upon the covering of the electrode. The current should not be allowed to permeate the tissues longer than absolutely necessary, for the reason given above, irritability increasing in proportion to the duration of application.

The faradic current should be used first in examination of nerve-trunks and motor points, and the fine or small electrode employed according to circumstances. Symmetrical points must be carefully selected, and, when properly located, had best be marked. It is then noted how much of the primary coil must be covered by the secondary to induce contractions, or how much of the cylinder must be withdrawn. If strong currents are necessary, the interrupting handle may be employed, in order to limit the duration of pain. The diffusion of currents to other muscles will often cause embarrassment, but this difficulty

may be much reduced by care. Upon finding the minimal contraction of muscles upon both sides, we may determine the character of contractions to both medium and strong currents, for the purpose of comparing contractions. DeWatteville suggests the use of a bifurcated reaphore, and thus alternately cause contractions first on one side, then on the other; he thinks better observations may thus be taken.

From the faradic, the same learned writer instructs, we advance to the galvanic current, and for the active electrode employ the small one, about ¾ inch in diameter; by means of a *dead-beat* milliampere-meter we note the strength of current required to produce a response. Always begin with the cathode active, interrupting the current occasionally, as required, and with this current particular care should be used to guard against electrotonic effects causing fallacies. In this way we, with considerable facility, determine whether or not the normal formula prevails, *i. e.* :—

$$\text{Ca. Cl. C.} > \text{An. Cl. C.} > \text{An. O. C.} > \text{Ca. O. C.}$$

All suspected muscles should be examined. The character of reactions, as well as their series, should be carefully compared with each other and with those of the opposite side, whether they react with a sharp, quick contraction, as in health, and whether they occur with a proper strength of current.

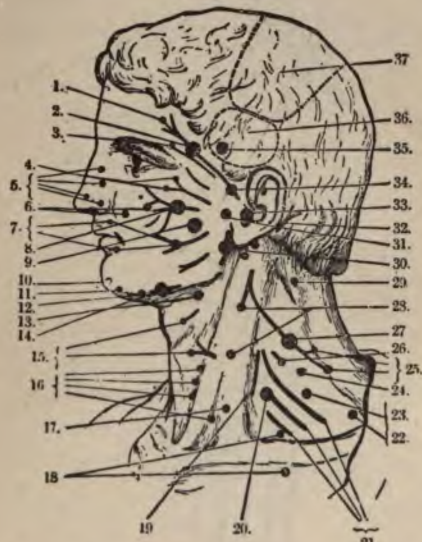
From what has now been laid before the student we trust it is fully understood that reaction of degeneration occurs only when the muscles are cut off from nervous communication with the spinal centre in the anterior cornu, whether the cause be in the cord itself or in the distribution of the nerve. In hysteria the electrical irritability is often exaggerated. Likewise, in disease of the lateral columns of the cord, and in cerebral lesions, the muscular contractions may be found exaggerated—*i. e.*, respond vigorously to slight stimulation. This is owing to the fact that the path from the brain to the cord is preventing the transmission of one of the highest functions of the former organ, inhibition, the same cause operating as in exaggeration of reflexes. The diagnosis of certain cord and peripheral lesions

of nerves from those of the encephalon is by no means least important in the various applications of this still obscure agent.

To Erb, more than to any one, we are indebted for a very complete scheme of "local faradization" of the motor nerves and of the muscles. The following illustrations and explanatory descriptive matter are taken from his work chiefly :—

Fig. 57. This illustration gives an idea of the situation of the face and head motor points ; the dotted points indicate the chief positions of stimulation. Fine active electrodes should be used.

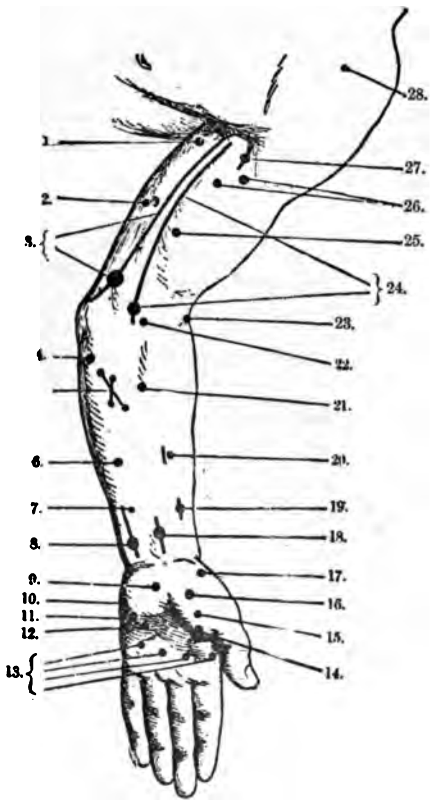
FIG. 57.



1. Frontalis. 2. *Facial nerve* (*super.*). 3. Corrugator supercil. 4. Orbicularis palp. 5. Nasal muscles. 6. Zygomatici. 7. Orbicularis oris. 8. *Facial nerve* (*med.*). 9. Masseter. 10. Levator menti. 11. Quadratus menti. 12. Triangularis menti. 13. *Hypoglossal nerve.* 14. *Facial nerve* (*infer.*). 15. Platysma myoides. 16. Hyoid muscles. 17. Omohyoideus. 18. *Ex. ant. thoracic nerve* (pectoralis major). 19. *Phrenic nerve.* 20. *Fifth and sixth cerv. nerves* (deltoideus, biceps, brachialis, supin. longus). 21. *Brachial plexus.* 22. *Long thoracic nerve* (serratus magnus). 23. *Circumflex nerve.* 24. *Dorsalis scapulæ nerve* (rhomboidei). 25. Trapezius. 26. Levator anguli scapulæ. 27. *Spinal accessory nerve.* 28. Sterno-mastoideus. 29. Splenius. 30. *Facial nerve* (*inf. branch*). 31. *Facial nerve* (*med. branch*). 32. *Post. auricular nerve.* 33. *Facial nerve* (*trunk*). 34. *Facial nerve* (*sup. branch*). 35. Temporalis. 36. *Third frontal convol. and insula* (centre of speech). 37. *Ascend. front. and pariet. convol.* (motor area).

Fig. 58 illustrates the motor points of the arm, forearm, and hand, flexor aspect.

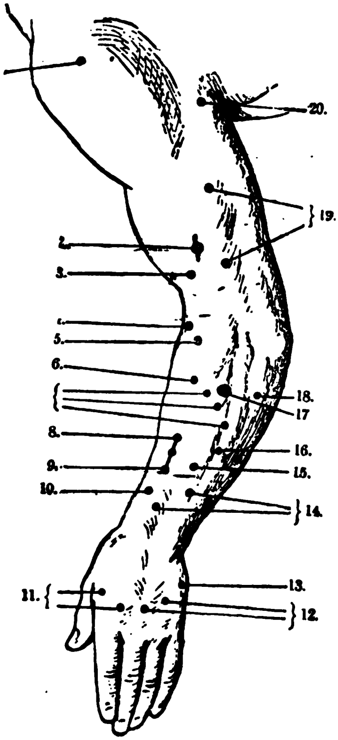
FIG. 58.



1. Triceps (cap. long.). 2. Triceps (cap. intern.). 3. *Ulnar nerve.* 4. Flex. carpi ulnaris. 5. Flex. dig. com. prof. 6. Flex. dig. (II. et III). subl. 7. Flex. dig. (ind. et min.) subl. 8. *Ulnar nerve.* 9. Palmaris brevis. 10. Abductor dig. min. 11. Flexor dig. min. 12. Opponens dig. min. 13. Lumbricales. 14. Adductor poll. brev. 15. Flex. poll. brev. 16. Opponens pollicis. 17. Abductor pollicis. 18. *Median nerve.* 19. Flex. poll. longus. 20. Flex. subl. digit. 21. Flex. carpi radialis. 22. Pronator radii teres. 23. Supinator longus. 24. *Median nerve.* 25. Brachialis anticus. 26. Biceps. 27. *Musculo-cutan. nerve.* 28. Deltoideus (ant. port.).

Fig. 59 illustrates the same as above, extensor aspect.

FIG. 59.



1. Deltoideus (post. port.). 2. *Musculo-spiral nerve.* 3. Brachialis anticus. 4. Supinator longus. 5. Extens. carp. rad. long. 6. Extens. carp. rad. brev. 7. Extens. comm. digit. 8. Extens. indicis. 9. Ext. oss. metac. poll. 10. Ext. prim. intern. poll. 11. Interossei dorsal. (I. et II.). 12. Interossei dorsal (III. et IV.). 13 Abduct. min. digiti. 14. Ext. sec. intern. poll. 15. Extens. indicis. 16. Extens. min. digiti. 17. Supinator brevis. 18. Extens. carpi ulnar. 19. Triceps (cap. ext.). 20. Triceps (cap. long.).

Fig. 60 illustrates the motor points of the thigh, anterior aspect.

Fig. 61 illustrates the motor points of the thigh, leg, and foot, posterior aspect.

FIG. 60.

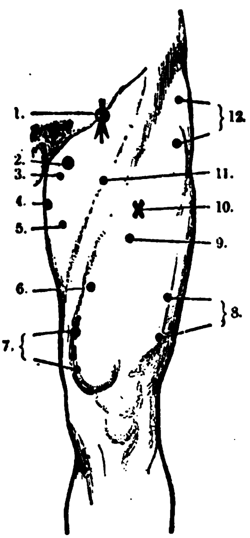


FIG. 61.

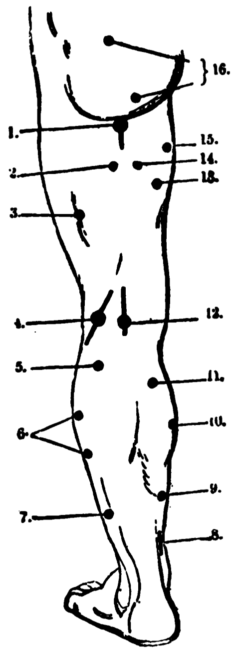
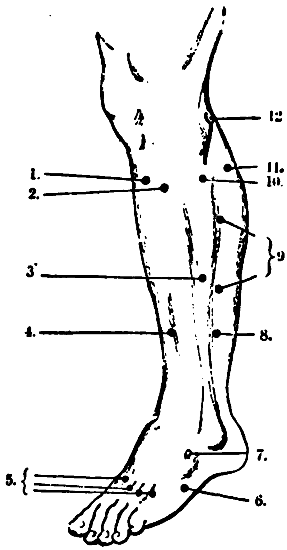


Fig. 60. 1. *Crural nerve.* 2. *Obturator nerve.* 3. Pectineus. 4. Adductor magnus. 5. Adductor longus. 6. Cruralis. 7. Vastus internus. 8. Vastus externus. 9. Rectus femoris. 10. Quadriceps (common point). 11. Sartorius. 12. Tensor vag. femoris.

Fig. 61. 1. *Sciatic nerve.* 2. Biceps femoris (cap. long.). 3. Biceps femoris (cap. brev.). 4. *Peroneal nerve.* 5. Gastrocnemius (cap. ext.). 6. Soleus. 7. Flexor hallucis long. 8. *Tibial nerve.* 9. Flexor digit. comm. long. 10. Soleus. 11. Gastrocnemius (cap. int.). 12. *Posterior tibial nerve.* 13. Semi-membranosus. 14. Semi-tendinosus. 15. Adductor magnus. 16. Gluteus maximus.

Fig. 62 illustrates the motor points of the leg, outer aspect.

FIG. 62.



1. Tibialis anticus. 2. Extens. digit. longus. 3. Peroneus brevis. 4. Extens. hallucis longus. 5. Interossei dorsales. 6. Abductor min. digiti. 7. Extens. digit. brevis. 8. Flex. hallucis long. 9. Soleus. 10. Peroneus longus. 11. Gastrocnemius. 12. *Peroneal nerve.*

PART II.

SPECIAL ELECTRO-THERAPEUTICS.

As has been before stated, notwithstanding the exceedingly large amount of investigation the subject has received and its accumulating literature, it is difficult to set an exact value upon the medical properties of electricity. The claims of the over-confident specialist and the depreciation of the therapeutic nihilist tend to create chaos in the minds of practitioners, who are compelled to obtain from the experience of others, rather than from their own, sufficient knowledge to properly treat cases in which it would appear electricity might prove of benefit. But few have the clinical facilities for personal observation in regard to this agent. The majority must therefore perforce look to the text-books for guidance, only, it must be confessed, to be misled too frequently by colored assurances of the power of this or that method of cure; specious conclusions, drawn with reprehensible freedom by "*post hoc ergo propter hoc*" reasoning. The therapeutics of electricity is based more or less upon empiricism, for, beyond its power to induce *muscular contraction*, but little is known with certainty as to its action in disease. The public, owing to the unprincipled claims of charlatans, as well, it must be added, as to the hasty, unsettled announcements of honest men, often look to this remedy with hope and confidence after faith in other treatment has departed; and, in truth, "after all said and done," upon consideration this fact need excite no special wonder, the tendency of many diseases being toward remission or resolution. Hence, inferences have doubtless frequently escaped that accurate, impartial, and judicial summing up so valuable to the practitioner.

Exact pathological diagnoses are very difficult to obtain, and in neurology, with the same data, equally well-trained observers may arrive at quite different conclusions as to the nature of the morbid process underlying a palsy or a spasm, so that, even when the modifying psychical factor is eliminated in both patient and physician, another often remains which tends to modify deductions.

The majority of investigators are now agreed that electricity is of far less service in cerebral and spinal disease than it is in peripheral nerve affections, such as neuritis and neuralgia, and that decidedly better results are thereby attained in functional and nutritional disorders than when the trouble depends upon organic change. In organic central affections its value is quite problematical.

The therapeutic field of galvanism is, of course, much wider than that of faradism. Faradism is of use mainly as a stimulator of muscle when still connected with the spinal nutrient cells. Galvanism has a widely extended range of usefulness, and stimulation of muscular contraction is but one, and oftentimes the least, of its uses; thus, we have its favorable influence upon nutrition and disease by means of its chemical, electrolytic, catalytic, and cataphoric action; probably, a most important effect may prove to be its power to bring (under proper management) medicaments into direct contact with affected parts, and thus to quiet pain and promote absorption.

Lack of space forbids us entering into a lengthy discussion of the theoretical effects of the currents in health and disease, or into a detailed account of all the many ailments in which electricity has been employed; nor would it be advantageous to the undergraduate, for whom this manual is principally intended, that we do so. We shall rather confine ourselves to a discussion of its applicability in those affections which the consensus of experience would indicate it is most useful.

As might be expected, faradism is of far less service than galvanism in cerebral disorders. Our usual object in resorting to electricity in brain affections is to modify nutrition rather than to excite nerve action; nevertheless, we cannot doubt the value of the reflex effects of faradism in central disease, obtained

through the stimulation of afferent nerves, thus promoting central changes.

Peripheral faradization with the wire brush or with the hand is thought to be not inefficient in cerebral hyperæmia, insomnia, and psychosis, also in cerebral hemianæsthesia. Mild faradic currents are applied to the head, with the expectation of beneficial results. In using the faradic brush or the hand, the area of skin over which either is applied must be thoroughly dry when the purpose is stimulation of the integument alone; but where deeper penetration is desired, and a more far-reaching action, the hand and the skin should be moistened, the hand being the electrode. When a mild current is preferred, the hand of the operator may well take the place of the brush, for in this manner the strength of the current can be best regulated, the sensation of the operator being the guide.

Faradization of the upper extremities and trunk, especially the abdomen, tends to produce cerebral anæmia.

In applying galvanism to the head, the electrodes should be large and flexible, and should be firmly applied to the part before the current is turned on through a current controller or rheostat; the galvanic current should then be gradually increased and carefully observed by means of a reliable milliampere meter in order that its strength be accurately noted. The current employed should at first be a weak one, less than one milliampere, and the sittings brief (½ to 3 minutes); sudden changes of polarity it is extremely important to avoid, save for the purpose of attaining special effects, and any sudden increase or decrease of current strength is equally to be shunned. At the end of the sitting the current must be gradually reduced to zero without altering the pressure upon the electrode.

The following are the usual methods of application :—

1. **Longitudinal Galvanization.**—A large flexible electrode on forehead, the other on occiput.

2. **Transverse Galvanization.**—Large or medium electrodes to bi-mastoid region.

3. **Subaural Galvanization.**—Medium electrode below ear; the other on opposite side of head, forehead, or upon the nucha.

4. **Diagonal Galvanization.**—Medium electrode to frontal,

fronto-temporal, or fronto-parietal region, and the other to the occipital region of the opposite side.

5. **Localized Galvanization.**—Medium electrode over the convolutions it is desired to galvanize, if the morbid process is superficial, the other on the opposite side of neck or below the ear. Several of these methods may be employed with advantage at the same *séance*. The polarity of the electrode should be attended to if it be especially desired to influence the cerebral circulation. If it is desired to increase the flow of blood to the brain, the anode should be applied to the neck and the cathode to the forehead. If an anæmic effect is desired, the reverse is indicated.

For localized foci of disease, Erb recommends transverse application of the current, so that the morbid process is in a straight line connecting the electrodes, the choice of pole depending of course upon the indication. To accelerate the circulation and dilate the vessels the cathode is applied to the diseased side ; to produce an opposite effect the anode should be placed over the diseased area. Localized morbid processes may also be influenced by longitudinal conduction from the forehead to the neck upon the affected side with the anode on the forehead.

So-called galvanization of the sympathetic (subaural galvanization) is of value in cerebral diseases. Its effects are exerted about the base of the skull, the vagus, and the cervical cord. This method has been already described. It has been thought well to apply on both sides, even though the lesion be unilateral.

Cerebral Affections.

Cerebral Hemorrhage, Softening from Thrombosis and Embolism.—Treatment should not be instituted until two to four weeks after their occurrence. Longitudinal, transverse, or oblique conduction of a mild *uninterrupted* galvanic current through the head, bringing the location of the lesion into a straight line between the electrodes, as nearly as possible, is the method to be pursued, the anode being placed upon the side of the lesion. It has been held that galvanism will thus tend to

promote absorption of the effused blood and improve the state of the cerebral circulation and nutrition.

Bilateral subaural galvanization is also of service. Peripheral faradization and galvanization of the affected muscles should also be employed. The faradic brush will benefit anæsthesia, should it be present, and aid the cerebral and peripheral circulation. Contractures are best relieved by mild faradization of the relaxed and paralyzed *antagonists* of the contractured muscles. Trial should also be made of stabile galvanization with the anode at the extremity of the contractured part and the cathode over the area of the cord whence the nerves of the stimulated muscles spring. Mechanical means are, however, usually of more service than electricity in relieving contractures of cerebral origin.

The various forms of brain galvanization described are of service, or that recommended by Althaus (central galvanization), in a recent paper on the treatment of cerebral syphilis, may be tried—*i. e.*, a large electrode to the epigastrium, a second smaller one then applied successively to the forehead, vertex, mastoid processes and cervical vertebræ, for ten to fifteen minutes daily, using a current of from one to five milliamperes. Where the lesion can be localized, as in the cortex, the exact portion should be more particularly acted upon.

Chronic Meningitis, Multiple Sclerosis, Hydrocephalus, Progressive Bulbar Paralysis.—Electricity is of very little service in these affections. Should it be tried, galvanism by the methods just laid down offers most hope. The progress of bulbar paralysis may sometimes be temporarily checked by persistent use of galvanism, stabile transverse conduction of the current through the mastoid processes, together with subaural and cervico-spinal galvanization, and galvanization or faradization of the paralyzed muscles. The movements of deglutition should be induced a number of times in a sitting by the application of one pole to the nucha, and the other over the larynx, and by securing frequent reversals of the current.

Psychical Disorders.

Psychical disorders, depending less upon organic change than upon functional, nutritional, or circulatory disturbances, are most benefited by electricity; and the earlier in the case it is resorted to the more decided is the benefit likely to result. In conditions of depression, such as melancholia, hypochondriasis, and stupor, good results are often obtained by peripheral faradization with the brush, or with large well-moistened electrodes; central, cerebral, subaural, and spinal galvanization also are beneficial.

Insomnia, so frequently an accompaniment of melancholia and hypochondriasis, is also benefited by general faradization and galvanism, applied as above.

In all conditions of depression it is better at first to make a trial of the cathode as the active pole. On the other hand, where irritation is a prominent symptom, the anode will perhaps prove more satisfactory in results. But, as stated in the first part of this work, should the desired benefit not accrue from this theoretical plan of procedure, no hesitation should exist in making trial of either pole indiscriminately. Electrical treatment should not be employed in cases of acute mania, or in conditions of general nervous hyperæsthesia, or in psychical hyperæsthesia.

General Neuroses.

Neurasthenia.—Galvanic, faradic, and static electricity may be employed, often with considerable advantage in neurasthenic conditions. The underlying cause should of course be removed, and appropriate hygienic and medical treatment supplement the electrical. Central, cerebral, subaural, and spinal galvanization are of much value. General faradization and galvano-faradization should also be tried, as should static electricity, especially the static charge. For painful spine, the anode of a strong galvanic current should be applied. The faradic brush is also of service.

Hysteria.—Electricity is of little value in the treatment of the general hysterical condition, save perhaps as a psychical agent, for which reason, as stated by Erb, confidence in the physician and the remedy is the best guarantee of success. Feeble currents and short sittings should be the rule. General faradization, faradic baths, general, central, subaural, and spinal galvanization are all recommended for the hysterical condition; their value, save through mental impression, is problematical. The local manifestations of hysteria—anæsthesia, paralysis, etc.—often yield with surprising readiness to electricity.

The chief points in the recognition of hysterical paralysis, apart from the accompanying symptoms of the hysterical condition, are the unaltered electrical reactions and absence of other wasting than that induced by the disuse of the affected part. Active faradic stimulation is indicated for the motor palsy. The accompanying anæsthesia is usually promptly dissipated by frequent employment of the wire brush. For hysterical hemianæsthesia, stimulation of a circumscribed area of skin on the forearm, as recommended by Vulpian, frequently produces brilliant results, the galvanic current being used.

Exophthalmic Goitre.—Excellent results are often obtained by the persistent use of galvanism in this affection. The usual methods of application are subaural, transverse, and diagonal brain and spinal galvanization.

For the exophthalmus, the current is passed transversely through the orbits, or one pole is placed over the closed eye and the other in the subaural region. The enlarged thyroid may be diminished by passing a current transversely through it, or by one electrode on the gland, the other below the ear. Weak continuous currents should always be used. Duration of sittings should be from five to ten minutes.

Chorea.—Electricity seems to have very doubtful permanent beneficial influence upon chorea, though it may be of some temporary service in lessening the jactitations. Subaural, spinal, and central galvanization offer the greatest promise of success.

It is very questionable if static electricity is of any value in this affection.

The Diagnostic and Prognostic Importance of Electricity in the Paralyses.

It will be remembered, from what has been stated in a preceding section, that the disappearing faradic irritability in the nerve and muscle, with serial and modal alteration to galvanism (degenerative reaction), enables us to tell indubitably that a paralysis is *not* cerebral in origin, but does not assist in the differentiation of a spinal from a peripheral palsy. These must be separated by other diagnostic means. Should a certainty exist as to the spinal origin of palsy, the electrical behavior of the affected nerve and muscle informs us as to the implication of the anterior cornual cells. The diagnostic importance of an electrical examination is beyond question. Electricity is also of immense value in prognosis. The severity and duration of a paralysis can often be told by it with positiveness. In slight peripheral-neuritic paralysis in which faradic and galvanic response undergo no change, a certainty of recovery within a month or so may safely be predicted. In paralysis of somewhat more severe type, with partial degenerative reactions, diminished faradic and galvanic response in the nerve, diminished or absent faradic response in the muscle, and with slight serial and modal galvanic alteration, but with only slight atrophy of the muscle, recovery may be predicted, but will not occur before several months have elapsed. When typical reaction of degeneration is present with decided atrophy, the paralysis is likely to be of many months' duration, and complete recovery may not occur; the greater the atrophy the more decided the electrical alterations, and the longer their duration the less the chance of recovery. When voltaic alternatives alone induce contraction in a markedly atrophied muscle, the probability of a restoration of function is slight indeed.

Diseases of the Spinal Cord.

Strong galvanic currents are necessary directly to affect the contents of the spinal canal, and these must be applied through

large, well-moistened electrodes. The position of the electrodes should be determined by the seat and character of the lesion. Should it be of small area, the electrodes may be placed but a short distance apart and a stabile current used. If it occupy a considerable vertical extent, one electrode should be placed at the cervical region, and the other held over the supposed lower limit of the lesion, or, better, made slowly labile over the affected area. If the upper part of the cord is to be galvanized one of the electrodes had better be placed in the subaural position, while the other rests upon the spinous processes of the lower cervical or upper dorsal vertebræ. It makes but slight difference which is the active electrode. In conditions of irritability and pain, however, the anode should receive preference. Usually it is better to use both poles alternately in order to secure the catalytic effect of each.

The cord may also be influenced reflexly through peripheral cutaneous irritation with the faradic brush or by general faradization, or with mild galvanic currents.

This latter method is often useful and provocative of benefit when the condition of the patient will not admit of strong currents being applied to the spine. There seems no doubt that peripheral surface irritation exerts a beneficial influence on the vascular supply and nutrition of the cord. Electrization of the cord and limbs should be combined in cases of paralysis having their origin in the spinal canal, as in atrophic spinal paralysis. A large flexible spinal electrode is placed in apposition with the area corresponding to the seat of disease; the other is applied labile to the peripheral muscles involved.

Spinal meningitis, in its chronic form only, is amenable to treatment by electricity. Where the exudate has caused considerable compression of the anterior nerve-roots, degeneration of these with paralysis and atrophy of the muscles enervated by them will result. These muscles should receive appropriate galvanic or faradic stimulation to obviate further atrophy. Of course, faradism will be useless if the muscles have already ceased to respond to its stimulation. While the affected nerve-roots should also receive attention, little can be expected from galvanism, or, indeed, any form of treatment. Where organ-

ization of the exudation has taken place, galvanism alone of all currents of electricity should be used, and even this would be efficient only through its electrolytic action ; and a current sufficiently powerful to exert appreciable effect in this direction could not be borne. In less severe forms of meningitis galvanism may be of considerable service in allaying irritative symptoms, and as a stimulant to circulation and nutrition in the affected area. The method of application would be the same as in myelitis.

Myelitis.—In the ordinary forms of chronic myelitis electricity, despite the assertions of over-confident electro-therapeutists to the contrary, is of scant efficacy, save through its influence on the paralyzed muscles enervated from the diseased area. Galvanism alone should be used for the central lesion by virtue of its catalytic effects and its influence on circulation ; in other words, on account of its theoretical effect upon nutrition. Though it must be admitted that the results of this treatment are not encouraging.

Galvanism may be used conjointly with other remedial measures which seem to be indicated. As before stated, a current of decided strength is necessary to reach the cord itself, upward of thirty milliamperes being required. Very large electrodes are, of course, necessary to enable this to be endured. Applications should be daily ; the duration from one to ten minutes, depending upon the strength of current employed. Stabile currents should be used and the polarity changed. In gradually diminishing and swelling the current care must be taken to avoid shocks. In compression-myelitis (secondary to vertebral caries) no benefit will result unless the diseased vertebræ first receive attention. In dorsal myelitis, the nutrition of the leg and thigh muscles being unaffected and the reflexes in excess, electricity is apt to be provocative of harm when applied to these extremities. Should the myelitis occupy the cervical or the lumbar region, active electrical stimulation may be required to prevent extensive atrophy in the extremities. Should faradic response be absent, the galvanic current only would be indicated. The large indifferent electrode should be held on the affected part of the spine ; the exciting or peri-

pheral electrode should be either the anode or the cathode, depending upon which obtains the more ready response.

In complete transverse myelitis the bladder and rectum are always affected. If the lesion is lumbar, there is paralysis of the sphincters with incontinence of urine and fæces; if above the lumbar region, there is also fæcal incontinence with intermittent or overflow incontinence of urine. In both, cystitis, with its accompanying symptoms, is apt to result. Electricity is often of decided service in restoring power to the bladder and rectum; galvanism and faradism are both of service. The current may be applied percutaneously (over the skin) or internally through the catheter-electrode. In the first method, should overflow incontinence be present, one pole is applied to the symphysis, the other to the lumbar spine; if simple incontinence, the first pole had better occupy the perineum. If sphincter and detrusor seem to be equally weakened, both applications should be made, or one pole may be placed on the symphysis, the other on the perineum. Strong stabile and labile galvanic currents should be used. Spinal galvanization and faradization should also be tried. By the internal method one electrode is placed upon the lumbar spine; the second, a bougie, insulated to its metallic tip, enters the urethra as far as the neck of the bladder in incontinence, but in retention it should be passed into the organ. It is important that this procedure should be undertaken under antiseptic precautions.

The bladder should contain urine or *another saline* fluid when *directly* electricized. Faradism or interrupted galvanism may be used. In rectal applications an olive-shaped metallic electrode is introduced into the rectum; the other pole is placed along the symphysis or on the lumbar spine.

In **anterior polio-myelitis** or **infantile palsy**, which is due to an acute inflammation of the multipolar cells in the anterior cornu of the cord, the electrical treatment should be carried out on the lines already laid down in the description of the treatment of meningitis and myelitis. Paralyzed muscles, the motor nerves of which spring from spaces of acutely degenerated anterior cornual cells, undergo rapid wasting, succeeding the degeneration of nerve-cells and nerves that arise from them. Faradic irrita-

bility in the nerve and muscle, and galvanic in the nerve are lost early; galvanic irritability in the muscle is increased for a time, but diminishes as the muscular fibres undergo degeneration, and finally, after a year or so, disappears coincidently with the complete degeneration of the affected muscle. Not infrequently some irritability returns after many months, due to partial recovery in certain muscular fibres. No degenerative reactions occur in those muscles which do not waste. Faradism is useless, for the muscles the seat of atrophy will not respond; galvanism should be alone used and persisted in patiently for months. Applications should be made daily of a current sufficiently strong to cause contractions in the affected muscles. In this way the progress of atrophy may be arrested and the muscles ultimately be in a condition to respond to voluntary nerve impulses when sufficient recovery has taken place in the cord to generate and nerve elements to transmit it. As suggested by Gowers, the application need only be made to those muscles in which the faradic irritability is *lowered* or *lost;* other muscles will recover without its aid. Treatment should not be instituted before the third or fourth week.

Progressive muscular atrophy, due to a slow degeneration of the ganglionic cells in the anterior cornu and their prolongations in the axis cylinder, is unfortunately but little amenable to electrical treatment. If it be used at all, a mild galvanic or faradic current (depending upon which induces better response) is indicated; one electrode over the affected region of the spine, the other upon the motor-point of the atrophied muscle or muscles. Subaural, central, and spinal galvanization may also be tried.

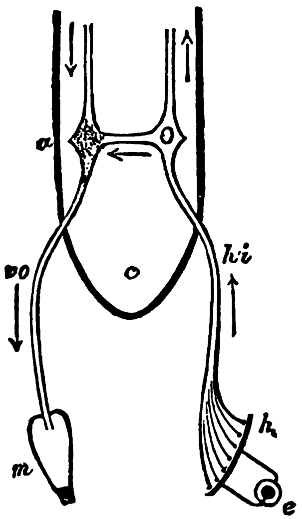
Spinal Sclerosis.—Electricity in lateral and disseminated sclerosis has accomplished little or nothing as a remedy. In the former, spinal and central galvanization may be used; in the latter, these, as well as subaural and the various brain galvanizations, offer the least chance of failure.

Faradism should not be administered in lateral sclerosis.

True cases of *posterior sclerosis* have been *reported* cured by spinal galvanization; also by peripheral faradization with the

brush, but we have never been able to note the slightest permanent benefit therefrom out of many cases subjected for long periods of time to the various forms of electrical treatment. As faradic peripheral stimulation of the skin, or of the underlying parts, with the object of reaching the centre through intact afferent paths, and thus influencing nutrition there, and reflexly affecting both central and peripheral lesions, is of unquestionable value in certain neural affections; it must be in this manner that the favorable results reported through the use of the wire-brush in posterior sclerosis were obtained, and the improvement reported as occurring after its persistent use for anæsthesia in cerebral disease has a like explanation. It is probably of value in myelitis and in neuritis. In anterior poliomyelitis, though the muscles supplied from the inflamed segment may not respond to faradism, it is nevertheless conceivable that cutaneous faradic stimulation may have a beneficial influence on the central lesion, and should at least be given a trial. The figure taken from Erb illustrates the path traversed by the electrical impression, the electrode applied at *e*.

FIG. 63.



Other Special Paralyses, Motor and Sensory, Optic Neuritis, and Secondary Optic Atrophy.

Encouraging results have been obtained from galvanization in optic neuritis and secondary atrophy. Erb recommends stabile currents, electrode primarily at the temples; then one on the closed eyelid anode in neuritis, but the cathode as soon as

signs of atrophy appear. The indifferent pole should be upon the nucha. Subaural galvanization may also be used with a large electrode and feeble current; sittings short (two to five minutes).

Paralysis of Ocular Nerves.—The methods just mentioned under the head of optic neuritis may be tried, and in addition the anode may be placed on the neck or above or below the eyelids, with the cathode over the closed lid. If faradism be resorted to, Erb recommends that the index finger, inclosed in wet linen, should be used as an electrode; current strength and duration of sitting same as above.

Paralysis of the Facial Nerve.

Rheumatic inflammation of the nerve within the Fallopian canal is the most common cause of this affection. In well-marked cases the palsy is apt to be decided, and of considerable duration. Reactions of degeneration are to be looked for with confidence, particularly where active treatment has not been promptly instituted.

The lesion will frequently be found in the canal just before the nerve emerges from the stylo-mastoid foramen.

In a class of much milder cases, the neuritis is found situated in a portion of the nerve after its emergence from the foramen. These cases are readily distinguished by less palsy, and by the fact that faradic and galvanic alterations do not occur, while recovery takes place in two or three weeks. On the other hand, in Fallopian neuritis the paralysis is a matter of grave importance. Taste is usually affected upon the anterior two-thirds of the corresponding side of the tongue; degeneration-reaction, partial, or complete, appears early, and recovery is delayed and often incomplete. Contractures and muscular twitchings may follow.

Midway between the light and the severe form is found a group of cases in which partial degeneration exists, and in which the prognosis is somewhat favorable, recovery occurring in a few months without subsequent contractures, etc.

By means of electricity a certain prognosis may be given as

to the duration of the paralysis at the end of the first week. *Normal nerve* irritability at this time may be taken to indicate recovery within three weeks. On the other hand, somewhat diminished irritability points to more serious disease, *i. e.*, four to eight weeks. Very markedly diminished neural response signifies a prolonged case and a tardy recovery.

Treatment.—Electrical treatment should be instituted at once upon complete subsidence of all inflammatory symptoms. The lesion itself should be the part first treated, either by direct very mild galvanization, or by means of the electrodes placed stabile in the auriculo-mastoid fossa or upon the petrous portion of the temporal bone. Galvanic or faradic stimulation of the trifacial may also be attempted. In any peripheral paralysis, where the stimulus cannot be properly applied directly to the proximal side of the lesion by reason of its situation, as in the Fallopian canal in facial palsy, electrical stimulation of an afferent nerve (in this instance, the trifacial) produces reflexly an efferent impression upon the proximal portion of the nerve, and thus serves to promote the removal of the obstruction in the nerve.

Peripheral treatment should consist in, preferably, galvanic stimulation of the affected muscles, the active electrode being the one from which the best response is obtained with a minimum strength of current (An. in R. De.). The anode or cathode is placed either behind the ear, or anteriorly in front of the zygoma, stabile; the other pole should be stroked along the course of the upper, lower, and middle facial muscles. One to two daily applications should be made of from five to fifteen minutes' duration. Even after faradic response returns in the severe forms of facial palsy, should the electrical treatment be continued, galvanic stimulation is preferable to faradic for reasons laid down in another section.

Electrical treatment is more likely to aggravate than to ameliorate spasms and contractures which occur in the later stage of the severe form of facial neuritis.

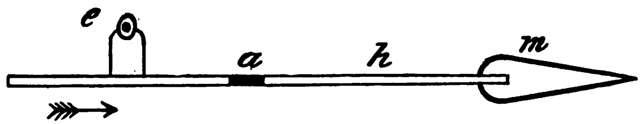
Hypoglossal paralysis is usually a symptom of bulbar paralysis, or of cerebral hemiplegia. In cerebral hypoglossal paralysis atrophy of the tongue and electrical alterations do not, of course, ensue. In nuclear or infra-nuclear paralysis

atrophy always occurs, and may be accompanied by degenerative reactions.

The *treatment* of hypoglossal paralysis must vary with the cause. If of nuclear origin, the treatment should be similar to that employed in progressive bulbar paralysis; if due to hemiplegia, cerebral galvanization may be tried. Peripheral treatment may be: anode at the neck; cathode at the motor point of the hypoglossal or directly to the tongue.

Musculo-spiral paralysis (not due to lead), and other peripheral pareses of the limbs, should receive faradic and galvanic treatment on the lines already laid down in the preceding pages. Should the paralysis be due to disease of the anterior cornu, the treatment would be similar to that given for polio-myelitis. If neuritic, a treatment similar to that indicated for facial palsy. If degenerative reaction is present, faradism is useless save for its reflex effect on the proximal side of the lesion. This should be reached, when possible, directly by galvanism and faradism, in order that the obstruction to motor conductivity may be the quicker overcome. As stated by Erb, frequent use of a motor-conducting path diminishes the resistance in the latter. Erb's

FIG. 64.



Schematic representation of a motor paralysis. *h*, motor-conducting path; *m*, muscle; *a*, site of lesion, obstruction to motor conduction; *e*, electrical irritant applied to central side of site of lesion.

words are: "In this manner we sometimes succeed in forcing the conduction of the process of excitation by means of the electrical current; when this has been achieved, the stimulus of the will may gradually grow effective and the paralysis disappear." The current should be applied as represented in the illustration, which is taken from Erb's work.

Daily stimulation of the paralyzed muscles with galvanism serves to maintain their normal contractility and to prevent

atrophy. It preserves them in condition, so that when power to conduct volitional impulses is regained in the nerve the muscles are in a condition to respond.

Lead Palsy. The most frequent form of paralysis due to lead is that involving the extensor muscles of the forearms. It is usually of subacute onset, the right arm being first affected, and then the left. The extensor communis is first paralyzed; then the extensors of the index and little finger; then the wrist extensors and the long muscles of the thumb, etc. The supinator longus escapes unless the paralysis extends to the upper arm muscles, which is not likely to occur until a late period of the disease. The affected muscles waste rapidly, and soon exhibit the reaction of degeneration. There is early loss of all irritability in the affected nerve and faradic loss in the muscles, while galvanic response in the muscles is at first increased, though modally altered. Soon *An. Cl. C.* = or > *Ca. Cl. C.*, and a continuous tetanic contraction is apt to be produced during the passage of the current.

The view that this paralysis is due to a primary change in the anterior gray cells seems most consonant with all the facts. The electrical treatment had better be that pursued in cervical cornual myelitis. The anode or cathode, depending upon which gives the more ready response, should be used peripherally on the paralyzed muscles, vigorous labile applications being made; while the other, larger electrode, should rest upon the lower cervical and upper dorsal region. This latter region should also receive special treatment by one electrode applied to it, the other to the sternum, a vigorous stabile current used, and, after a moment or so, a change of polarity. Subaural galvanization should also be used. It is possible that both galvanic and faradic, especially the latter with the wire brush, peripheral stimulation, has a beneficial effect in "wrist drop," through a reflex influence on the multipolar cells.

Diphtheritic Palsy. Paralysis of the muscles of the palate, pharynx, eyes, and extremities is not infrequent after diphtheria, due to a neuritis or anterior polio-myelitis.

Treatment. Central and subaural galvanization should be used as well as local stimulation of the affected muscles. In

paralysis of the extremities the method should be the same as that just indicated for lead palsy. Paralysis of the ocular muscles should be treated as described on a former page. The palatal muscles may be directly stimulated by the application of small catheter-shaped, covered, and well-moistened electrodes to them. Feeble currents only should be used.

Stabile currents also should be passed transversely through the cheeks, or through the auriculo-mastoid fossæ. Movements of deglutition should be induced in paralysis of the pharynx by the application of the anode to the upper part of the nucha, and the cathode labially to the laryngeal region. With each Ca. Cl. the act of swallowing will take place.

Cardiac weakness, should it occur in diphtheria, may be successfully combated by the use of galvanism in conjunction with stimulants, strychnia, etc. A large electrode is applied to the cardiac region—another to the dorsal vertebræ, and a strong current, rapidly reversed, used. Subaural galvanization is also of service in diphtheritic heart failure.

Anæsthesia. The treatment of anæsthesia should be directed to the removal of the cause of the interference with sensory conductions, whatever that may be. The usual treatment of the anæsthetic condition itself consists in stimulation of the insensible area with the faradic brush—the skin having been thoroughly dried, and afterward preferably dusted with powder. Galvanism may also be used with the cathode labile over the anæsthetic part.

For HYSTERICAL HEMIANÆSTHESIA, see HYSTERIA.

The Electrical Treatment of Neuralgia and other Painful Affections.

Electricity is often of the greatest value in the relief of pain. Galvanism is especially of service. Its action is chiefly calmative, the production of anelectrotonus being the cause as generally accepted. Perhaps, however, the catalytic effect of either pole, the positive equally with the negative, is as much concerned as the sedative influence of the anode in the benefit

resulting from the patient use of galvanism[1] in neuralgiform ailments. Faradism is chiefly of service in neuralgia through its counter-irritant and reflex effects, the latter especially on the vaso-motor and trophic system of nerves. It may be applied either with the faradic brush, the sensitive surface being stimulated until a decided hyperæmia is induced, or, through moist electrodes, a strong current being used. The "swelling" faradic current is often of decided benefit in neuralgia, the current being gradually increased and diminished while the electrodes are *in situ*.

When galvanism is resorted to, stabile currents should first be tried, with the anode upon the painful nerve-trunk or over a painful point. The application should be strong, very gradually increased and diminished, without alteration of pressure or making interruptions. Should the desired effect not be obtained with one pole, the other may be tried.

The best results seem to be obtained when both electrodes are applied to the course of the nerve, the cathode being peripheral in location. Several applications may be successively made along the course of the nerve, with the electrodes, when possible, about 25 cm. apart. Erb commends this plan. It is particularly serviceable in SCIATICA. In this disease (which in many cases is rather neuritis than neuralgia), perhaps the best method of procedure is to place the anode over the situation of emergence of the nerve from the sacrum. The cathode is placed lower down on the nerve, at first at the sciatic foramen, then about mid-thigh. Following this, in the popliteal space, etc., over the peripheral distribution of the nerve; or the more purely polar method may be tried. Erb has had good success with it. The cathode is placed upon the anterior surface of abdomen or thigh, while the anode is applied stabile to the various parts of the nerve, such as vertebræ, plexus, sciatic foramen, and to the points *douloureux*. A few interruptions of the current should be made at

[1] The secondary current (of, preferably, very fine wire), rapidly interrupted, should alone be used when a sedative effect is desired. To produce muscular contractions either the primary or secondary current may be used.

the termination of the application to relieve the stiffness of the muscles apt to be present in chronic cases. The electrodes should be large and well moistened, and upwards of 30 or more milliamperes used. Applications, as in the treatment of all the neuralgias, should be at least once daily of from 5 to 10 minutes duration.

The various special neuralgias may be treated on the lines already laid down with or without success, depending upon their severity and the underlying cause. The latter always should be ascertained and removed when possible.

Anodal diffusion, a method depending upon the cataphoric power of electricity, has recently come into vogue for the treatment of localized neuralgia. Solutions of cocaine, aconite, belladonna, chloroform, and other drugs have been resorted to with more or less success in the production of anæsthesia in superficial pains. Cocaine is the most promising agent. A flat metal electrode, preferably of platinum, or, in its absence, nickel-plate surrounded by a rubber rim, may be used to apply the medicament in solution placed upon a disc of tissue paper, to the desired point. The electrode is connected to the positive pole, and a current strength of from 5 to 20 milliamperes allowed to pass for about 10 minutes.[1] It is questionable if this method be better in results, while it is doubtless more troublesome than hypodermic medication at the site of pain. A method, which seems to the writers as worthy of trial, is that of following the hypodermic injection of the drugs used to secure local anæsthesia by a stabile application of the anode of a strength of current and duration similar to that mentioned above. This would appear to be productive of more prompt and decided results than by the other method.

Muscle pains due to rheumatism or strain are often removed with surprising promptness by electricity. Lumbago is a type, and will often well illustrate the curative effects of electricity, yielding, as it frequently does, to one or two applications. This treatment is markedly successful with recent cases.

[1] For a full description of the method see "A Further Study of Anodal Diffusion as a Therapeutic Agent," by Peterson.—N. Y. Med. Record, Jan. 31, 1891.

cotton and collodion. The patient should be in recumbency, and remain so at perfect rest for several hours afterwards.

For a more detailed description of the method of electrolysis in aneurism the reader is referred to the excellent work of Bartholow.

The *Loreto-Barwell* method of treating aneurism, that of the introduction of fine silver wire into the sac, together with the employment of electrolysis, has yielded excellent results after the method of electro-puncture alone, failed.[1]

In the **Treatment of Urethral Stricture** by electrolysis, a method devised by Dr. Robert Newman, of New York, may be used. A properly insulated bulbous metallic sound of a calibre somewhat greater than the stricture, connected with the *negative* pole, is introduced to the site of constriction, the anode being placed on one of the thighs, a current of three to eight milliamperes is used for upwards of ten to fifteen minutes, repeated at intervals of five days (or longer), the frequency of application depending upon the results obtained. After the current has been flowing a short time, the electrode should be made slowly to pass the stricture, if practicable, without undue force. Should there be much pain or subsequent inflammatory reaction after the application, the parts may be bathed in hot water and a morphine and belladonna suppository inserted into the rectum.

The **Simple Inflammatory Stricture** seems most amenable to electrolysis, but we believe this method of treating strictures has scarcely yielded the results at first claimed for it.

Eneuresis (nocturnal and diurnal) often yields promptly to electrical treatment. If galvanism is used, the anode should be applied to the lumbar cord and the cathode to the symphysis and perineum, with a current strength of from 5 to 10 milliamperes, for from 2 to 5 minutes, once or twice daily. Erb recommends, in girls, the application of a small sponge (or absorbent cotton) covered electrode between the labia, close to the meatus; in males, to introduce a wire electrode about 2 cm. into the

[1] See a case of Rosenstine (Amer. Jour. Med. Sciences, Jan. 1891), in which two operations of electrolysis (70 milliamperes, 20 minutes) were without effect, but which were subsequently *cured* by the Loreta-Barwell operation.

urethra, the other pole to the lumbar vertebræ. The faradic current is then passed for several minutes. In obstinate cases it may be requisite to faradize the neck of the bladder.

Functional Weakness of the Male Sexual Organs (Impotence, Spermatorrhœa) requires both galvanism and faradism, especially the former in impotence. The anode, a large-sized electrode, should be applied to the lumbar spine and the cathode (medium electrode) in one groin after the other, stabile and labile, then about the upper and lower surface of the penis, and finally on the perineum. The entire application should consume several minutes, and the current be of medium strength. In nocturnal pollutions stabile rather than labile currents should be used with the anode in preference to the cathode about the genitals. The urethral electrode may be used for the purpose of direct applications to the orifices of the ejaculatory ducts.

In **Conditions of Atony (with or without dilatation) of the Stomach,** with diminution in the secretion of the gastric juice, percutaneous, and especially intra-gastric faradization has yielded excellent results. Intra-gastric faradization requires for its application a special electrode. Eichorn[1] recommends a small, bulbous, hard-rubber capsule electrode, designed by himself, and termed a "deglutable stomach electrode," which has

FIG. 65.

proved very satisfactory in his hands. The stomach should contain a half-pint or so of fluid, in order that the current may be diffused. The electrode is swallowed. The indifferent electrode may be placed upon the back to the left of the seventh

[1] Medical Record, May 9, 1891.

dorsal vertebra, or on the epigastrium, or may be held in the hand. Marked results are often obtained from faradization thus applied in chronic gastric catarrh, gastric atony, and in gastric dilatation. Einhorn reports also pure cases of gastralgia much improved from galvanism similarly applied. Fig. 65 represents the stomach electrode, manufactured by Otto Flemming of this city. In the hands of the writers it has given perfect satisfaction.

Catarrhal Jaundice, Splenic Enlargement, and **Ascites** frequently respond to faradization of the gall-bladder and abdomen generally. Contractions of the gall bladder may not unlikely be due to reflex action. Such results seem not improbable from results obtained in cases of catarrhal jaundice by means of percutaneous applications.

In **Leukæmia** and **Malarial Splenic Enlargement** percutaneous faradization is also worthy of trial.

Constipation, when due to atony of the intestine, is usually relieved, at least temporarily, by galvanism, faradism, or galvano-faradism. A suitable hygienic regimen must be combined with electrical and drug treatment, in order to obtain permanent benefit from electricity. It may simply be looked on as a valuable adjunct. If galvanism be resorted to, the anode (medium electrode) should be applied to the lumbar region; the cathode (large electrode) along the course of the colon, from right to left. Previously it is well to make application to the region of the small intestines, and ultimately over the whole abdomen; the electrode, applied to the latter region, should be held firmly in place, especially in the neighborhood of the cæcum and sigmoid flexure. In addition to the above, Erb recommends transverse passage of the current from one hypochondrium to the other, the electrodes to be pressed firmly into the parts. Should this treatment fail, an olive-shaped electrode, well insulated, save the tip, may be passed into the rectum, the other being placed in the lumbar spinal region or upon the abdomen, as directed above. With the electrodes in this position, frequent changes of polarity must be made to avoid cauterization of the rectum, and also to secure vigorous contractions of the abdominal muscles.

Galvanization of the lumbar spine may also be resorted to; also faradization in much the same method. Applications should be daily, and continue during the space of five to twenty minutes.

DISEASES OF WOMEN.—Extraordinary results have been obtained, in recent years, in the treatment of these diseases, by electricity. The subject has attained such proportions that it cannot be noticed here in more than the barest outlines. The student is referred for details to the writings of Apostoli, Keith, and others, and especially to the excellent manual of Massey, from which many of the following points are taken.[1]

The faradic battery is often useful for general stimulation in women the subjects of "nervous prostration," and as a sedative or a stimulant to the uterine functions and organs, depending upon the form of current or force used. As it is frequently desirable to use conjointly the galvanic and faradic currents in general electrization, it is best to have an arrangement in the switch-board whereby this combination can readily be effected. Static electricity is far less useful in gynæcology than either of the other forms, and can be replaced by them. It is of most service as a surface stimulator, the spark having but limited penetrating power.[2] It will, however, readily pass through dry clothing, and is useful, therefore, when muscle and skin excitation is desired without removal of the garments. Static electricity is regarded by Dr. Massey as an agent of unique value in the treatment of the backache of nervous women, unassociated with definite pelvic trouble. Special electrodes are necessary for the application of electricity (galvanism and faradism) in gynæcology. When strong galvanic currents are used, the external electrode must be of considerable size.

For currents over 100 milliamperes the clay electrode of Apostoli, or one of the modifications of it suggested in the books, should be employed. For currents of less strength Massey suggests a pad of absorbent cotton or of folded towels of the same size as the clay electrode, thoroughly wet and connected

[1] Electricity in the Diseases of Women.

[2] This has been denied of late, but not with sufficient evidence.

with a metal disc through which the current flows. A very large pad, such as is used for general and spinal electrization, will also answer very well. The intrauterine portion of the uterine electrode, which is to be connected with the positive pole, must be of platinum to avoid corrosion or dissolution due to the action of nascent oxygen and acids upon it. That used with the negative pole being unattacked thereby, may consist of ordinary nickel.

The positive pole produces a firm eschar, such as results from use of a caustic acid. It is used principally to control uterine hemorrhage and to remove cervical stenosis.

Cauterization by the cathode produces more or less liquefaction of the tissues acted upon, and as a result of this, absorption is supposed to be more decided than from the action of the anode.

In **Electro-puncture** a strong, spear-shaped needle, as a rule, connected with the cathode and insulated to within half inch of its point, is used for penetrating the tissues.[1] The galvanic current unquestionably has power to promote the dissolution of some forms of fibroid tumors, especially of the less firm varieties. Intrauterine cauterization is always to be preferred to puncture when the situation of the tumor admits of the concentration of the current upon it. According to Massey, electro-puncture is best reserved for two emergencies. The first of which, by the way, is rarely encountered: *a*, When the cavity of the intramural tumor cannot be entered; *b*, when a subperitoneal tumor has its uterine attachments so stretched as to place it beyond the effect of intrauterine application. When puncture is resorted to, it should be done through the vagina in preference to through the abdominal walls. Whether puncture or intrauterine cauterization is resorted to, the same strength of current is used. The electrodes are first placed in position and the current gradually increased to the desired strength, from 50 to 250 milliamperes, and then gradually diminished. Whole dura-

[1] Massey states that about 200 milliamperes, concentrated at the exposed one-half inch of a negative needle, will destroy an area of this length and one-fourth inch in diameter in the muscular tissue of a cadaver in two minutes.

tion of application from two to ten minutes, depending upon the strength of current used. It should be repeated once or twice weekly.

In **Menorrhagia** and **Metrorrhagia**, due to relaxation of the uterus, intrauterine faradization seeems to be more efficient than anodal galvanization.

In **subinvolution, with relaxation,** faradism is equally useful. The single or bipolar intrauterine electrode may be used.

In **Chronic Metritis** and **Endometritis,** with accompanying leucorrhœa, negative cauterization of the uterine cavity is of the greatest value. A current of from 10, 20, or more milliamperes[1] is passed for from 5 to 10 minutes, once to twice weekly, and usually effects a cure in a short time.

Cervical Stenosis, causing **dysmenorrhœa,** is treated successfully with galvanism. An electrode insulated to within an inch, or thereabouts, from its distal extremity, and capable of being fitted with metal tips of varying sizes, is pressed against the constriction, the indifferent electrode upon the hypogastrium, and a current of from 10 to 30 milliamperes passed for a few minutes until the smallest sized tip penetrates the constriction. Application should be about twice weekly, and, as in the local treatment of all uterine affections, between the menstrual periods only.

In **the Congestive** and **Ovarian,** or **Nervous forms of Dysmenorrhœa,** abdominal or dorsal galvanization and faradization are often of the greatest service. In the more unyielding forms of congestive dysmenorrhœa, mild intrauterine galvanization (cauterization) and faradization should be used.

Amenorrhœa has also been treated by abdominal galvanization and faradization, and remarkable success recorded. *The method* is unipolar, intrauterine, or vaginal application of either current. If *galvanic*, the cathode must be the active pole.

Galvanism and Faradism have been often successfully resorted to, to cause the death of the fœtus in *extrauterine pregnancy*, and if employed prior to the third month, they offer greater promise of success than any other treatment.

[1] Apostoli uses upward of 200 milliamperes.

Treatment.—An insulated, bulbous electrode is placed either in the vagina or rectum in apposition with the sac. The other electrode, large and well moistened, should be in position against the cyst externally. The electrical current should be of moderate strength and of a few minutes' duration. Daily applications should be made until it is believed that life has ceased in the fœtus. Bartholow recommends slow interruptions of the faradic and occasional anodal, or cathodal openings of the galvanic. He regards faradism as less efficient than galvanism, and somewhat dangerous, through the powerful contractions of the abdominal muscles induced by it, thereby threatening rupture of the cyst. A large abdominal electrode would obviate this risk.

Most obstetricians prefer faradism to galvanism, as the faradic applications, when of any strength, are less painful than the galvanic, which also must be interrupted.

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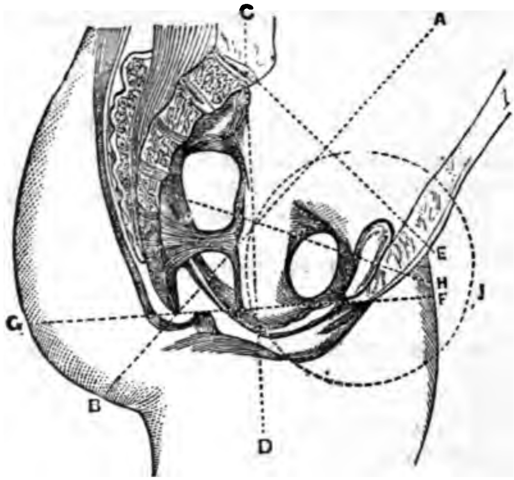

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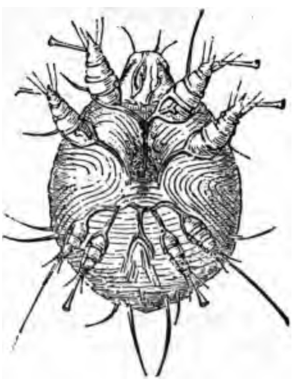

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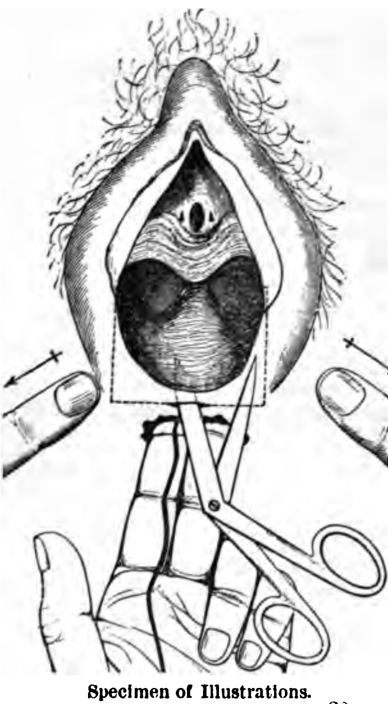

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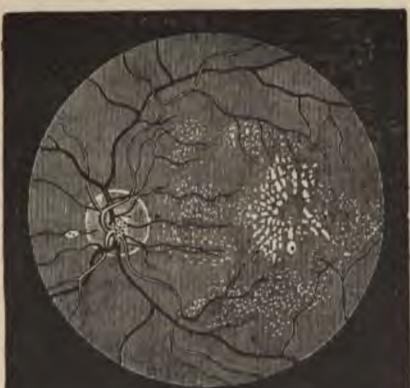

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